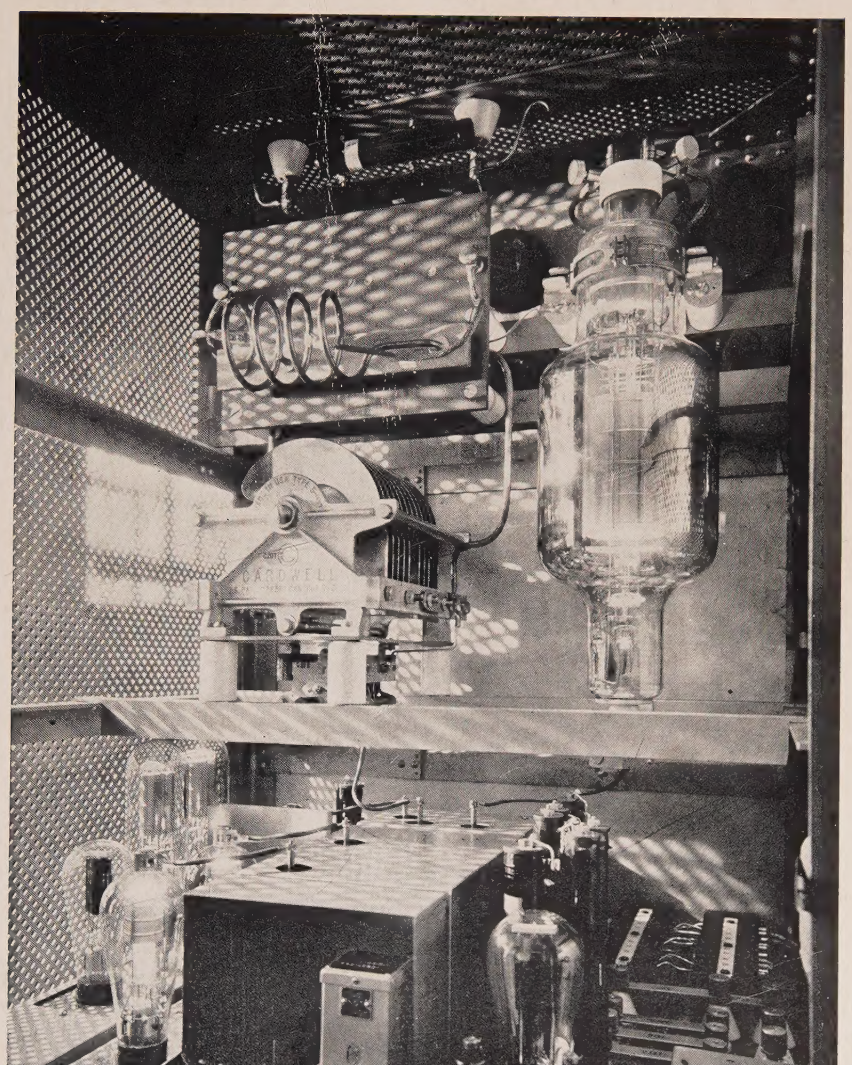
Electrical Engineering

March
1934



Published Monthly by the
American Institute of Electrical Engineers

Mr. Institute Member:

The messages to you in this space appearing from month to month have been for the purpose of enlisting your aid in maintaining and increasing Institute membership.

The report of the Membership Committee as of February 1, 1934 showed results as follows:

Applications for membership received during January 1934 - - - - - - - - -	179
Applications for membership received May 1, 1933 to January 31, 1934 - - - - -	455

You can continue to help your Section Membership Committee by sending to them the names of those who you feel should be invited to join the Institute.

Everett S. Lee

Chairman National Membership Committee

Published Monthly by

American Institute of Electrical Engineers

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Electrical Engineering

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17,500

This Month—

Front Cover

Interior of one of the transmitters built in the Bell Telephone Laboratories, Inc., for the Central America radiotelephone service.

Educational Series—No. 4

Special Articles

A.I.E.E. Papers

News of Institute and Related Activities 496

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Discussions of A.I.E.E. Papers

Communication

Education

Electric Furnaces

Electric Power Switching

Electrical Machinery

Instruments and Measurements

Power Distribution

Power Transmission

Protective Devices

Transportation

WINTER CONVENTION DISCUSSIONS. Discussions of the winter convention papers received before February 5 and which have been approved appear in this issue. Discussions subsequently received up to March 1, and which have been approved, together with the authors' complete closures if received by March 15, will be published in the April issue. This will constitute the bulk of the winter convention discussions. Subject to review and approval, contributions received after March 1 may subsequently be published provided they are sufficiently pertinent, but they may not be included within the authors' closures.

BACK ISSUES WANTED. Copies of the November and December (1933) issues of Electrical Engineering are required to meet the demand for these back numbers. If you care to dispose of your copies of these issues please mail them to American Institute of Electrical Engineers, 33 West 39th St., New York, N. Y., printing your name and address upon the enclosing wrapper. Twenty-five cents will be paid for each copy returned.

The Story of the Institute Budget

A Presentation of Facts and Figures

By E. B. MEYER
FELLOW A.I.E.E.
Chairman A.I.E.E.
Finance Committee

THROUGHOUT the past several years, as a result of the general depression in business which has affected practically every activity, the matter of control of expenditures has required most careful consideration. To both individuals and organizations, the general curtailment of income has presented most perplexing problems, the proper solutions of which have been found only through painstaking analysis of all items of expense and the effecting of economies, where possible, in regular operating costs.

The American Institute of Electrical Engineers, in company with all such professional societies and like institutions, has been confronted with the many difficulties that have arisen out of this situation. On the finance committee and the board of directors has rested the responsibility for budgeting the total annual expenditure on such a basis that it would come within the limitations of the anticipated income and, at the same time, give the greatest possible latitude to those who were directing Institute activities that are essential to the furthering of its aims and in the interest of the members and their professional work.

In such periods of business recession, it is absolutely essential that everything that is done contribute to a strengthening of the foundation upon which will be laid future plans. At no time in its history has the Institute indulged in extravagances; but if, under such economic conditions as exist at present, the maximum contribution is to be made to its members who support it, every policy and every procedure must undergo the critical scrutiny of those who are endeavoring to retain those activities which are the most significant.

Such a subject is controversial and frequently the cause of much discussion on the part of the membership. In all such situations, lack of a complete understanding of facts and figures leads to misunderstanding and sometimes to complaints on the part of some who have at heart only the best interests of the Institute. Therefore, some of the problems as they have been presented to the board of directors, together with a brief outline of the steps toward solution as taken by the finance committee, are set forth for the purpose of acquainting the membership with items of major consideration and to show the effort that consistently is being made to maintain the high standard of service which the Institute always has striven to render to its members.

The extent of the contribution that can be made by any organization such as the Institute is determined by the soundness of its business policies. The furtherance of its aims, to promote technological advancement and the best interests of its membership, is predicated upon its ability so to manage its affairs that it may foster uninterruptedly those activities that are consistent with the purposes for which it exists. It is important that its members be qualified technically, if advances in the electrical art are to be made, but it is just as important that the members have knowledge of the financial aspects of the Institute's affairs if they would be equally qualified to promote the well-being of the institution which concerns itself not only with technical matters, but also with the improvement of the professional status of those engaged in electrical engineering.

Annual Budget and Income Statement

The nature and relative importance of the various items that make up the annual budget perhaps are known to but few members not actively identified with the Institute's financial affairs. In Table I, therefore, are presented the actual expenditures for the year 1931 and the budget of expenditures for 1934, respectively, and this, in addition to listing the items of which the budget consists, makes a comparison which shows the effectiveness of the steps that have been taken consistently since 1931 to make reductions wherever possible.

It may be noted that in the last 3 years there has been a falling off of more than 40 per cent. Of importance, therefore, is the comparison between the anticipated income for 1934 and the budgeted expenditures, and whereas no attempt has been made to analyze every one of the latter items in detail the following discussion of the more important activities is presented in order that the members not only may be acquainted with the conditions, but also may know what purpose guides those who are directing the affairs of the Institute.

Furthermore, it is believed that such knowledge will lead to the conviction that if the Institute is to continue to render service, those activities which promote the accomplishment of its purposes cannot be curtailed unduly, and that it is incumbent upon every member to do all within his power that will in any

way contribute to the successful operation of Institute affairs.

Reserve Capital Fund

This fund had its inception in 1921 when the board of directors voted that 5 per cent of the annual income should be reserved, if possible, as a working capital fund to be used in certain contingencies. The plan was not unanimously approved, there being some members who questioned the justification for a reserve capital fund at any time and who believed that the Institute was obligated to expend each year its entire income for those activities considered to be of major interest to the membership. Fortunately, this view was not general, with the result that the Institute has been able to contend with the contingencies which have developed during the past several years.

A factor with reference to the fund which should be mentioned is that its existence is largely due to the profits derived from the advertising section of the official monthly publication, which since 1921 have amounted to $450,000. The very great decrease in the amount of advertising revenue during the period of the business depression is therefore directly related to the withdrawals from the reserve capital fund.

The book value of this fund, as of September 1930, amounted to $218,847.88. During the ensuing period the fund was reduced by the sum of $64,319.63, leaving a net book value on May 1, 1933 of $154,528.25.

Of this reduction, $19,673.75 represents a reserve within the fund that has been created to offset doubtful investments which are in default of interest payments; $7,492.27 comprises losses in exchange or sale of securities; the remainder of approximately $37,000 is the actual withdrawal from the fund to cover deficits from operations and special appropriations authorized by the board of directors.

It is gratifying to note, however, that the ratio of market value to book value is more than 70 per cent, indicating the very conservative attitude on the part of those responsible for creating this investment fund, as many other funds have depreciated in value to less than 50 per cent.

Table I—Comparison of Expenditures for Year Ending September 30, 1931, and Budget for Year Ending September 30, 1934

The results of steps taken to reduce expenses are shown, but unless present estimates of 1934 income are exceeded a portion of the reserve fund, as indicated, will have to be used to maintain membership activities at the present standard

Expenses	Expended Year Ending 9/30/31	Budget for Year Ending 9/30/34	Per Cent Decrease
Publications			
Text matter	$116,611.58	$67,000.00	42.5
Advertising section	24,518.55	10,500.00	57.1
Year Book	9,381.07	5,600.00	40.3
Institute meetings	15,594.45	10,000.00	35.8
Institute Sections			
Appropriations	23,573.24	14,000.00	40.6
Convention and other expenses	13,549.04	7,800.00	42.4
Institute Branches	13,174.17	6,700.00	49.1
Administration			
Headquarters' salaries	48,640.32	31,000.00	36.2
General (postage, printing, supplies, etc.)	15,218.55	12,000.00	21.1
Membership	8,507.19	6,000.00	29.4
Traveling expenses, general	10,212.86	4,250.00	58.3
United Engineering Trustees			
Building assessment	5,713.56	3,000.00	47.4
Engineering Societies Library	10,420.23	8,380.00	19.5
Engineering Societies Employment Service	1,226.22	4,000.00	+226.0
American Engineering Council	17,615.25	7,625.00	56.7
Standards committee	7,824.70	5,825.00	25.5
Other committees and miscellaneous expenses	16,887.71	9,335.00	44.7
	$358,668.69	$213,015.00	40.6
Income			
Dues	$209,402.16	$129,500.00	38.1
Students' fees	13,159.50	6,500.00	50.6
Entrance fees	7,841.75	2,400.00	69.3
Transfer fees	1,565.00	800.00	48.8
Advertising	67,195.97	20,000.00	70.2
Electrical Engineering subscriptions (nonmember)	9,478.23	8,000.00	15.5
Transactions subscriptions	12,058.12	3,500.00	70.9
Miscellaneous sales	9,634.56	4,500.00	53.2
Revenue from badges	2,706.50	1,000.00	63.0
Interest on securities	11,791.40	8,800.00	25.3
	$344,833.19	$185,000.00	
Withdrawal from reserve capital fund	13,835.50		
Cash available from sale of securities, authorized by the board of directors in January 1933		15,665.00	
Amount which may have to be drawn from reserve capital fund unless income estimate is exceeded		12,350.00	
	$358,668.69	$213,015.00	40.6

Changes in Publication Policy

There is perhaps no other single activity of the Institute that concerns the individual member in so intimate a way as does the publication policy, which determines the character of the official monthly publication, Electrical Engineering.

The adverse effect of recent economic conditions upon the revenue producing phases of the Institute's operations is clearly shown in the foregoing statement on income. The falling off in membership and the considerable decrease in the return from advertising have necessitated a substantial reduction in the appropriation for publication purposes. Advertising, one of the largest of income producing items, dropped from approximately $85,000 in 1930 to less than $17,000 in 1933, a reduction of 80 per cent.

The problem which is constantly before the responsible committees, therefore, concerns the determination of a publication policy that will give the greatest and most tangible return to the members for the dues that they pay. About a year ago a comprehensive survey was undertaken to find out what modifications might be made in the publication policy that would enable the Institute to serve its membership most effectually and at the same time keep the cost within the limitations of the restricted budget. As a result of this study the publication committee proposed at the June convention in Chicago, last year, a unified program which subsequently was approved by the board of directors at its meeting in August 1933.

Beginning with the September 1933 issue and in subsequent issues of Electrical Engineering this new publication policy was presented in detail. Briefly, the new plan will afford practically a 100 per cent increase in the amount of technical material supplied to the membership at large, at a considerable reduction in the actual gross total cost.

The publication budget, it may be noted, is less

than 60 per cent of the amount 3 years ago, and is lower than it has been at any time since 1919–1920. In spite of this, however, the new policy will increase tremendously the effective publication service to the individual member.

In recognition of the forthcoming celebration of the Fiftieth Anniversary of the Institute on May 13, of this year, it is planned to enlarge the May issue of ELECTRICAL ENGINEERING and to develop it into a suitable memorial volume. It is intended that this issue shall record the life and activities of men prominent in Institute affairs, as well as the electrotechnical advances of the period. The issue will probably contain approximately 200 pages and, to achieve the desired results, a special appropriation of $2,000 over and above the normal publication budget has been provided. Such additional expense will, it is anticipated, be more than offset by the return from special advertising which should find this issue attractive because of its character and permanent reference value.

Reduction in Section Appropriations

With the presentation of the budget for 1931–32, the board of directors suggested to the Sections that they accept a voluntary reduction of 10 per cent and thus contribute to the effort to allocate equitably the anticipated income to the various activities planned for the year. In the 2 ensuing years the increase in the suggested voluntary reduction to 20 per cent was similarly caused by financial circumstances and was, in effect, the alternative to a revision of Institute by-laws to provide for smaller appropriations.

Section 48 of the by-laws has provided since 1922 that each Section shall receive in the aggregate a sum not to exceed $175 plus $1 for each member who resides within its territory at the beginning of the administrative year. During the past several years of economic stress, the board of directors has not wished to amend that section, as it has been hoped that the appropriations to the Sections might soon be restored to the full amounts. It therefore invited the Sections to coöperate and thus make unnecessary the establishing of a mandatory limitation.

It has been the desire at all times to support Institute Sections as liberally as circumstances would permit, and this is evidenced by the fact that a comparison of the average Section appropriation, taken from the most recent financial statements of 3 other national engineering societies with similar Section organizations, shows the Institute's average appropriation to be larger by 30 per cent, 125 per cent, and 225 per cent, respectively. The reductions in Sections appropriations since 1931 have, therefore, been suggested by the board of directors in a sincere effort to allocate the funds to all important activities on a fair basis.

Administration

There has been developed at headquarters a highly trained and efficient working staff which has made possible an expansion of the activities from year to year without the corresponding necessity for increasing the number of employees on the staff. Already it has been established as a fact that the routine work incidental to the maintenance of membership under the present conditions and the recent changes in publication policy have called for even more clerical work than was required in former years.

The records indicate that during the past years of prosperity, only moderate increases in compensation have been granted, and that almost 40 per cent of those now employed have been connected with the Institute for a period of from 12 to 29 years.

Details of administrative expense are given in the following items:

Salaries includes the full salary of the national secretary and the office manager, and a proportion of the total salaries paid to other employees of headquarters' staff......	$31,000
GENERAL EXPENSES	
Postage is charged with cost of mailing communications to the general membership, such as dues, bills, and statements, election ballots, routine correspondence, miscellaneous announcements, committee notices, etc............	5,000
Stationery and Printing is charged with cost of all stock, plain and printed, used in carrying on routine activities; also for miscellaneous supplies not chargeable against specific appropriations..............................	3,000
Office Equipment absorbs part of the replacement cost of office furniture and equipment............................	500
Miscellaneous Expense absorbs such charges as telephone service, telegrams, insurance, cartage of mail, typewriter supplies and inspection, engrossing diplomas, check tax, and miscellaneous office supplies and headquarters' expenses..	3,500
Total appropriation..................................	$43,000

As a result of a decrease in the personnel and a reduction in salaries, the total annual expenditures for headquarters' payroll has decreased from $112,452, as of October 1, 1931, to $71,290 at present, a reduction of 36 per cent. As a matter of fact, the payroll of the headquarters' staff 7 years ago was $3,000 more than it is at present in spite of the fact that in 1926 the editorial staff consisted of 3 people at an annual salary of $8,640, whereas the editorial staff consists today of 5 people at a total annual expenditure of $15,506, the latter total being $2,500 less than that authorized by the board of directors when certain changes in publication policy were approved.

Membership Committee

The membership committee, under the active and enthusiastic leadership of the chairman, Everett S. Lee of Schenectady, N. Y., is quite optimistic of the results which it expects to accomplish during the year; not only in stimulating new member applications, but in bringing back into the fold those who, having found it necessary to drop out for a time during the past few years, are now finding that they are in a position where they can restore to themselves their Institute standing.

Under present conditions the membership committee is called upon to exert even greater efforts than formerly to maintain the membership, but, despite this fact, the expenditures of the committee for the present appropriation year will have to be less than in

previous years. The committee is engaged diligently in carrying on the usual campaign to obtain new members, and notwithstanding existing conditions has succeeded in obtaining an appreciable number of new applications.

The detailed estimated expenses of the membership committee for the 1934 budget are as follows:

Printing of application and endorsement forms; national, Section, and committee stationery, etc.	$ 500
Pamphlet list of Members and Fellows	75
National committee notices to membership	500
Follow-up correspondence to members in arrears, prospective applicants, Enrolled Students	800
Notifications of election	50
Payments to Institute Sections for portion of entrance fees of new members	900
Miscellaneous postage and other expenses	525
Salaries of clerical force	2,650
Total appropriation	$6,000

Reduction in Traveling Expenses

In the adoption of the 1934 budget, which again provides for a mileage rate less than that which has been allowed in earlier years, the board of directors was influenced by the following considerations:

1. The decrease in the amount of funds available for this purpose.

2. The probable general adoption by the railroads of a lower mileage rate.

3. The desire to provide traveling expenses for the maximum number of Institute activities. The 1933–34 budget contemplates the expenditure of 21.8 per cent more for traveling expenses incurred for Section and Branch work than was expended in 1932–33.

The budget provides for one meeting of each District executive committee to be held within the district, and to be attended by the vice-president, the district secretary, and either the chairman or the secretary of each Section within the District, or, if neither can attend, an alternate chosen by the Section executive committee. Provision is also made for occasional visits of the vice-presidents of the Institute to the Sections and Branches within their geographical Districts.

To afford a proper understanding of the various allowances for traveling expenses in the budget, the items are tabulated below and show the totals on the basis of 5 cents per mile, with the exception of the appropriation for the national nominating committee, approved on the basis of 10 cents per mile:

Section delegates to summer convention	$ 3,100
Counselor delegates to summer convention	550
Conference on student activities in each geographical District	4,000
Geographical District executive committees	750
Vice-presidents	500
Board of directors	2,000
National nominating committee	1,000
Total appropriation	$11,900

At the conference of officers, delegates, and members held during the summer convention in Chicago, June 1933, the following resolution was adopted:

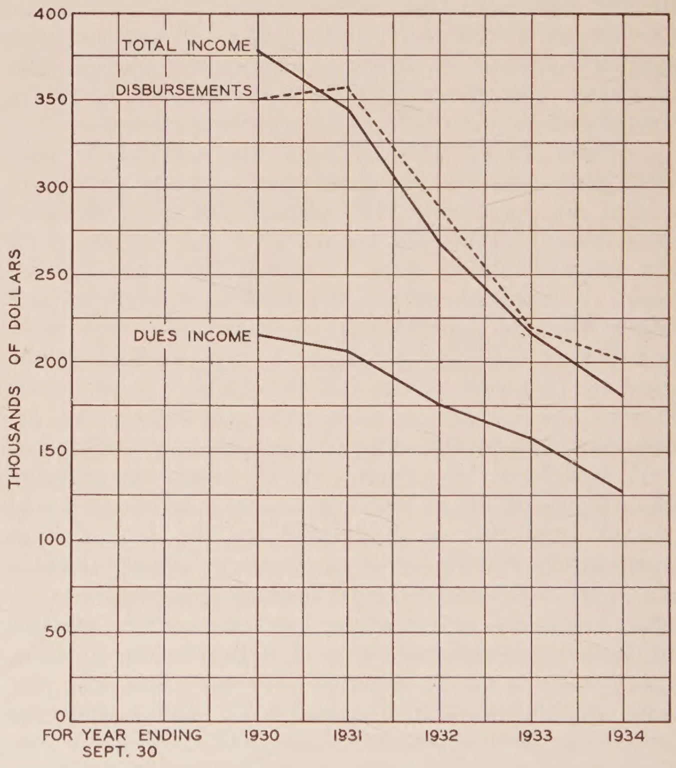
Resolved: That it be recommended to the board of directors that in each future annual budget sufficient funds be allocated to insure the continuance of the annual District student activities conferences, and that the travel allowance to such meetings in any year, for one student chairman and one counselor from each Branch, be made at the same rate as may be in force for the Section delegates and others to whom travel allowances are granted.

The board of directors, at its meeting held on June 28, 1933, voted to refer this resolution to the finance committee for consideration. Upon receipt of the finance committee's favorable recommendation, the board of directors authorized a special appropriation of $4,000 to permit, at the 5-cent mileage rate, of a conference in each of 9 geographical Districts.

At the October meeting, the board of directors resolved that during the year beginning October 1, 1933, the number of meetings of the board of directors be decreased in order to reduce expenditure for traveling expenses to such meetings, and that meetings of the executive committee may be substituted at the discretion of the president.

Engineering Societies Library Maintenance

The Engineering Societies Library is one of the most important coöperative activities of the 4 national societies of civil, mining, mechanical, and electrical engineers. As a composite, thoroughly indexed, and conveniently arranged library developed



Annual Institute income and disbursements since 1929

The extent to which the annual revenue from dues and from other sources has been reduced in the four years since 1929, and the probable income from these sources for 1934, call for vigorous effort on the part of membership committees and others who may render assistance in this most important matter. It is expected that general business improvement will, before long, have a favorable effect on the character of this chart. The consistent lowering of annual operating costs each year since 1930 is indicative of steps taken to keep such costs within close approximation of the funds provided by the total annual income.

from the individual libraries of these 4 societies, it is well prepared to serve effectively in virtually the entire field of engineering.

Each society, in the development of its technical publications, constantly has endeavored to supply to its members the most desirable technical material originating in its own division of engineering, and thus has enabled them to keep in close touch with technical progress of the types in which they are especially interested. However, even in its own division, no society can hope to supply all the technical material which its members may desire. By their coöperative support and development of a single library of large proportions, the engineering societies have made readily accessible to their members the world's best engineering books and periodicals, and yet the total cost to each society has been moderate.

The service bureau of the library is prepared to supply information in written form, such as photostats, reports on searches, and translations. Thus it meets the needs of many members, regardless of their location, who do not have access to a good engineering library or who do not find it convenient to do their own library work.

The book lending service of the library enables members located anywhere to borrow virtually any current American engineering book at a charge of 5 cents per day plus transportation charges.

A library agreement approved in 1928 by the Founder Societies and the United Engineering Trustees, Inc., provides for the apportionment of contributions for the support of the library among the 4 Founder Societies on the basis of an equal contribution from each plus an additional contribution from each society based upon its membership. The Institute budget for the present appropriation year contains an allotment of $8,380 for the library.

American Engineering Council

The majority of the members are familiar, it is believed, with the development of American Engineering Council from the time that a joint body, Engineering Council, was created by the 4 Founder Societies in 1917 for the purpose of establishing an agency to deal with matters of common interest to engineers and to serve as an instrument for contact between engineers and the general public in so far as such matters concern the engineering profession and the public welfare. Fundamentally, this body provides the means whereby unified action may be taken when necessary either to promote a more enlightened public opinion or to safeguard in a proper way the interests of the members of the engineering profession.

The original body, having headquarters in New York, received financial support from each of the societies to the extent of $4,000 annually; reference to the printed records of the Council for the years 1918 to 1920 will reveal the extent of the achievements which were possible with this organization.

The organization of American Engineering Council in Washington and the transfer to this body of Engineering Council activities occurred in 1920, at which time the 4 constituent societies agreed to contribute financial support on a membership basis of $1 per member. The payments made by the Institute since that time to and including 1933 have averaged $16,500 annually. The budget for 1934 provides for an appropriation of $7,625. Of this amount $3,125 represents the obligation for the last quarter of 1933 and the balance is for the nine months of the budget year of 1934.

Council has, over the past 2 years, sharply curtailed expenses and the reorganization plans for 1934 contemplate still further curtailments. President Whitehead, in a letter to the chairman of the A.I.E.E. finance committee, under date of January 13, 1934, wrote as follows:

> I have just returned from the meeting of the Assembly of the American Engineering Council and have been more than ever impressed by the importance of the work that it has done in the past and the functions planned for it for the future. There was unanimous recognition by all of those present that the best interests of the profession of engineering are being well conserved within Council and that it is at present most representative as well as a most efficient mouthpiece.

That there are many exceedingly important movements which require engineering guidance is evident to anyone conversant with present day affairs, both economic and political. That these movements may have an exceedingly important influence upon the future of the engineering profession is obvious to any student. Perhaps never before in the history of the profession did it need, more than at this time, a central, authoritative, coöperatively supported agency which can deal effectively with public questions and all similar matters which concern the engineering profession.

Only through the deliberations of such a body can the best interests of the great profession of engineering and of its members be served and procedure formulated under which engineers may make their greatest contribution to all constructive and forward-looking national movements. To Council, therefore, both moral and financial support should be given. If this is done, Council will be enabled to exert its influence properly toward maintaining the integrity and well-being of the profession to the ultimate benefit of all of its members.

Standards Committee

From the original position of having practically complete control of electrical standardization work (which was held from 1906 to 1924 approximately) the Institute's responsibility now has developed into that of both originator of new and desirable standardization projects and guide in the development of such projects up to the point where they are ready for approval as American Standards.

Practically all American Institute of Electrical Engineers' projects are developed, however, under the direction of the Institute's standards committee or its various technical committees, with the knowledge and coöperation of the standard-making bodies of other engineering organizations. By such a development procedure, carried on entirely under the auspices of the Institute, it proves possible in many instances eventually to offer and to obtain approval

as American Standards for many specifications, standards, and codes, which otherwise would be held up for long periods if forced into the necessary formal procedure which governs the activities of sectional committees of American Standards Association. The current series of test codes now in process of development under American Institute of Electrical Engineers' procedure is an example of this nature.

The preliminary work of compilation necessarily involves appropriations by the originator and by the sponsor organization sufficient to cover the clerical and production expenses of each new project throughout the various stages preceding final adoption, whether the project is carried forward by an agency, a sectional committee, or by a subcommittee of the Institute's standards committee.

At its meeting held January 22, 1934, the board of directors of the Institute adopted a resolution urging that ". . . provision be made for the necessary and adequate technical standardization and research activities of the [U.S.] Bureau of Standards in the electrical field so that it may continue its valuable contributions to the art and industry. . . ." This resolution was published on page 357 of the February issue of ELECTRICAL ENGINEERING.

Engineering Societies Employment Service

The amount appropriated for Engineering Societies Employment Service over the past 4 years has had, of necessity, to be materially increased. Under normal conditions this service has practically paid for itself, but with the decline in the number of placements made, due to the lack of positions available, the Institute has been forced to accept a larger share of the expense of providing this employment facility. The appropriation of $1,200 in the 1931 budget has been increased to $4,000 for 1934.

Miscellaneous Expense

The details of the item of $9,335 for other committee and miscellaneous expenses in the 1934 budget are as follows:

American Standards Association	$1,125
President's appropriation	1,250
Finance committee (expense of audit)	400
Code committee	60
Technical committees	150
Edison Medal committee	100
Membership badges—inventory account	750
U.S. National Commission, I.C.I.	300
Miscellaneous printing	2,500
Retirement salary	2,700
Total appropriation	$9,335

Year Book

For economic reasons it was not deemed advisable to publish the year book in 1932 or 1933, the last edition having been published in 1931. In spite of this, however, during each of the 2 years it has been necessary to expend approximately $2,000 to cover the clerical cost of maintaining (whether or not a year book is published) the mailing and business records of the membership.

Although the omission of 2 editions of the year book has not appeared to have caused any general dissatisfaction on the part of the membership (the reason for omission no doubt being understood) an average of 100 requests monthly has been received during the past several months for copies of an edition later than 1931.

As the headquarters staff was not in a position to furnish a membership list to applicants for membership who requested this for use in selecting their sponsors (and this naturally affected the work of the national membership committee) nor to furnish such lists in convenient form for the use of Institute committees and officers of Institute Sections, it was the belief of the board of directors that to remedy this situation a year book should be published this year to give a list of members with business and mailing addresses as recorded on January 31, 1934.

This year book will be new in style and will contain an alphabetical list of members with reference to the state and town in which the desired complete entry of each member can be found. Under this arrangement the catalog of members appears in geographical order, which style conforms more nearly to the requirements of Institute committees and Section officers, affording an opportunity to determine readily the business affiliations of members in any particular locality.

Members' Responsibility

The foregoing discussion brings to the attention of the membership the nature of the problem that ever is before the members who constitute the managing bodies of the Institute, and also the studious effort that is being made to give the various phases of Institute life the degree of emphasis that each deserves. The responsibility that rests on those Institute members who, in their official capacities, direct such matters and strive to maintain a sound financial status of the Institute certainly is, in some respects, greater under present economic conditions than ever before. It is, therefore, all the more important that the individual members realize this, and give serious thought to possible ways in which they may render assistance to their officers and committee heads.

What then should be the attitude of a member of the Institute? As was pointed out by President Whitehead in his recent message to the membership (2nd cover, ELECTRICAL ENGINEERING, Nov. 1933) the concern of a member should be "*what can I do for the Institute?*"; with assurance he may expect to participate in full measure in those benefits that will come to each member as a result of a concerted effort on the part of all to contribute in every possible way.

The respect in which any particular member may render assistance to the general welfare of the Institute is not easily definable and will vary with circumstances and with the opportunities that may present themselves to any given member. In one case it may be seeking out new members, or stimulating renewed interest on the part of those who are indifferent or apathetic. In another, advantage may be taken of opportunities to induce members who are inactive to take a more prominent part in activities

for which they are fitted. Again, a constructive suggestion may be made with regard to some respect in which economies might be effected.

Over and above all of these things which may be regarded as specific contributions, however, do we find the question of *attitude* as the one major responsibility. The professional and material welfare of every member is, as President Whitehead has pointed out, "intimately bound up with that of the Institute. The work of the Institute cannot be curtailed, its resources cannot be impaired, without ultimate detriment to the professional and material well-being of each of its members." If, then, the attitude of each member is all that it should be and evidences acceptance of the fact that "the American Institute of Electrical Engineers is an organization through which electrical engineers are united for conserving and expanding the opportunities open in the profession, for the elevation of its standards, and for the stimulation and improvement of the professional equipment of the individual member," then will the Institute be enabled to go forth with assurance to meet whatever new problems may be presented by future conditions.

Scientific Thought and Social Reconstruction

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Scientific men cannot stand aside and ignore the vast political and social experiments being conducted during the present period of accelerated social change. It is not necessary or even desirable, however, that professional scientific men abandon their laboratories and attempt to deal with executive problems; but it is necessary that they expound insistently the nature of scientific thought and study its application to social and political problems. Engineers and scientists are urged to deal with problems of social reconstruction as they deal with other problems, pinning their faith on those methods of reasoning that have proved so successful in analyzing all types of natural phenomena.

CONCERNED AS HE WAS with the design and production of industrial machinery, Doctor Steinmetz realized that the increasing use of that machinery must have a profound effect on the social, economic, and political relations of men, and he was speculating constantly as to the future of our machine civilization. In commemorating his work, therefore, at this crisis in human affairs, it seems appropriate to turn for a short time from the consideration of technical scientific progress and to dwell on the reaction that progress is having upon the life of mankind and upon the relation of the scientist to that reaction.

In the change that recently has come over our theories of the nature of the physical universe, nothing is more striking than our abandonment of the necessity for continuity in physical phenomena. We no longer insist on the representation of all phenomena by differential equations, and we are content to accept the view that many phenomena are essentially discontinuous in their nature. Discontinuous phenomena, however, often have their origins in continuous phenomena that are antecedent to them. For instance, the slow changes that occur in the earth's crust, involving the rise of one portion of the crust in relation to another, produce steadily increasing strains which suddenly are relieved by a slip which produces an earthquake.

Full text of the Eighth Steinmetz Memorial Lecture delivered before the A.I.E.E., Schenectady (N. Y.) Section, Jan. 10, 1934. *Not published in pamphlet form.*

In the same way, the steady changes in knowledge and technique that occur in human society from time to time produce a state of strain which can be relieved only by a transition period of rapid change. Such transition periods have occurred often in the history of the world, and there have been rapid changes both in relation to the material control that man has over his environment and also in relation to the economic and social structure of society. Frequently, these changes have been accompanied by great mass movements of peoples, resulting in the destruction of nations and the erection of new empires on the ashes of the old. Between the fourteenth and the twelfth centuries B. C., such a great change resulted in the destruction of the oldest stable empires of which we have any record. The origin of that change we do not know. It was quite possibly the culmination of climatic changes in the great plains of Eastern Europe and Western Asia. In the course of it, Crete lost her control of the northern Mediterranean and finally vanished from the list of the empires. The Archaean Greek civilization which Crete had founded disappeared in its turn. The Hittite Empire, attacked in the north, pressed through to the south, came into conflict with Egypt and finally with the new power of Assyria, and was destroyed. Assyria conquered Babylonia and expanded its new empire, which was eventually to overrun Egypt itself. It was perhaps at that time that the predecessors of the

Romans swept into Italy, and that the great Celtic invasions of Britain and Gaul occurred.

In the fifth century after Christ, a similar rapid change in the organization of world power and consequently in the economic and social life of the civilized world took place. The Gothic invasion of Italy, with the transfer of the empire from Rome to Constantinople, terminated the domination by Rome of the western world.

At the present time, the rate of change is greater than any in the previous experience of man, and it appears still to be accelerating.

In the fifteenth century again, feudalism came to its end, and the social system that had ruled the world for a thousand years deliquesced and changed before the eyes of man. At the same time, the people of Northern Europe largely abandoned the traditional religion of their forefathers and established a new church, which carried with it altogether new and different social relations.

Portentous as these changes were, and rapid as they seemed at the time, they were, nevertheless, extremely slow in comparison with the changes we have seen and now are witnessing. The 2 earlier changes mentioned took several centuries to accomplish, and even the more rapid change at the close of the Middle Ages took more than a hundred years to complete. Compared with any of these, the great industrial revolution of the nineteenth century, when machinery and factory organization took the place of hand labor and the home industry, was extremely rapid; but that whole century saw less change in the life of man than the first third of the twentieth, and within our own lifetimes we have seen changes in method and technique that will affect the economic and social organization of society to perhaps as great an extent as the whole of the changes made from the neolithic period to the beginning of the twentieth century.

At the present time, the rate of change is greater than any in the previous experience of man, and it appears still to be accelerating. The origin of this change is, of course, the development of our knowledge of nature, that knowledge which we classify under the general heading of "science"; and so long as our increase in scientific knowledge continues to accelerate, the resulting change in social and economic conditions also will accelerate. At the present time, the proportion of human effort devoted to the acquisition of new scientific knowledge is increasing each year; but it is still only an infinitesimal part of the activities of mankind and only a very small part of the amount of energy that might be expended upon the development of science if that were thought generally to be worthwhile.

The production of scientific knowledge causes changes of great importance in our economic and social life; these changes lag very much behind the production of science so that as a general rule the science being applied today is not the science produced today, but the science of which the fundamentals were discovered a number of years ago. As the rate of production increases, the period between a scientific discovery and its application diminishes, and whereas it took us 50 years to apply Faraday's discovery of electromagnetic induction, such discoveries as the electronic tube have been applied on a world wide scale within 2 decades; and at the present time perhaps we may be considered as applying generally scientific discoveries of only 10 years ago. The much greater production of scientific knowledge at the present time, however, means that the application of science to industry and, still more, its effects on our economic and social life will continue to increase even if the amount of scientific discovery in the near future does not; and there is every probability that the latter also will continue to increase.

This rapid change that is going on in human affairs, having the curious characteristic that it is continuously increasing in rate, may be compared with an autocatalytic reaction in chemistry. An autocatalytic reaction is one in which a product of the reaction increases its rate, so that if you put all the materials into a vessel and start the reaction going, it will begin slowly and then increase in rate and go faster and faster as the products accumulate. Such a reaction ends in a complete conversion of the system into a new form. Sometimes, the rate increases so much that the reaction becomes explosive and the new form is entirely different from the original system. Sometimes, after a period of violent reaction, the system settles down into a new and stable form. No system that is changing at an increasing rate, and especially no system in which the product of the reaction increases the rate of change, can be stable.

The conditions that made necessary adjustments and changes in the social order arose from the growth of science; scientific men must feel that they have a special responsibility for the correct orientation of the social system toward those conditions.

In our present system, it seems that the very scientific knowledge produced tends to increase the rate of change; and it is therefore probable by analogy, although it is not at all certain, that our social system is in an unstable stage and that after a period of rapid change it will settle into a new and stable phase which will endure until some new cause provokes another period of change. What that stable system may be and how it can be stabilized, since we must assume that scientific discovery will continue, is impossible for us to foresee; but certainly that change cannot continue to occur at an ever increasing rate.

During the period of activity in which we find ourselves at the present time, many experiments are being conducted; new social systems are being evolved, and new economic methods are being tried. The corporate state under a fascist dictatorship and the corporate state under a communist dictatorship are only 2 of the more striking experiments that are being conducted at the present time, with mankind at large as the subject of the experiment and with the happiness and lives of mankind dependent upon the success of the experiments.

It is clear that scientific men cannot stand aside from these vast political and social experiments and ignore them, restricting their interest merely to protests when such experiments are likely to affect their personal interests. The conditions that made necessary adjustments and changes in the social order arose from the growth of science, and scientific men must feel that they have a special responsibility for the correct orientation of the social system toward those conditions. Moreover, there is a technique of experiment and that technique must be learned. It is not a natural gift of mankind. Any one who has watched experiments carried out by men untrained in the methods of science will know how costly and wasteful such experiments are likely to be; and if social reconstruction is to be undertaken as a series of vast experiments, it is desirable, at any rate, that those who conduct the experiments will have been trained in the technique of experimentation. It was this that led Professor Miles Walker in his address to the engineering section of the British Association in 1932 to call on the engineers to manage the world. He felt that if the engineers—in which term for brevity he included all scientific men—took a greater part in world management, they would make a greater success of it. He suggested that actual experiments in the form of self-supporting colonies consisting of groups of 100,000 people should be formed under the auspices of engineers and economists. Again, Sir Frederick Gowland Hopkins in his presidential address to the British Association at Leicester this year reminds us of the indictment that the command of nature has been put into man's hands before he knows how to command himself, but he suggests that this is an indictment of mankind and not an indictment of science.

To me, however, an indictment of mankind seems quite useless. If we cannot indict a nation, how can we indict a species? We must play the game with the cards that are dealt; we must reconstruct society with men as they are. We must assume the probable behavior of mankind as we assume the properties of any other material we have to use, and we must find our solution assuming that the behavior will continue. The scientist, then, as I see it, cannot retire into his shell like a medieval monk or, as the classical Latin grammar story put it, "Balbus, having tweaked the dragon's tail, went away." Nor do I agree with Professor Walker that it would be wise for the scientist to attempt to take up the burdens of the politician or the statesman. It is imperative that he continue to carry out his own work, from which may come the salvation of mankind. The special work of the scientist is the creation of ordered knowledge which is then available for use by all mankind; but in this special work he employs a special method and he approaches his problems in a special spirit, and this method and spirit constitute, I believe, the special contribution of science toward social reconstruction.

It is imperative that the scientist continue to carry out his own work, from which may come the salvation of mankind.

In the last 20 years, a great change has come over the technical industries of the world and especially of the United States. That has been ascribed, probably with justice, to the great expansion of industrial scientific research. However, I do not believe it is the actual work done in the industrial research laboratories that has produced the change; it is rather the growth of the scientific spirit in all sections of the industrial organization. Executives of modern technical industry have been trained in the methods of science and they face their problems with a scientific attitude. In order that the scientific spirit should be used in government, it is not necessary or even desirable that professional scientific men abandon their laboratories and attempt to deal with executive problems; but it is necessary that they expound insistently the nature of scientific thought and study its application to our social and political problems.

Once before in history, the application of scientific methods to the theory and practice of government almost was realized. In the golden age of Greece, the great group of philosophers, of whom the most perfect expression was to be found in the work of Aristotle, had made a truly scientific approach to the problems of nature. Then, the destruction of the philosophic spirit during the period following the wars of Alexander, the rise of the materialistic military empire of Rome, and finally the destruction of almost all the culture of the old world, with the downfall of the classical pagan religion, brought the advance of scientific thought to an abrupt end.

Throughout the Middle Ages, the authority of the written word almost completely displaced first-hand observation and experiment in the search for truth. The revolt against authority arose in the early sixteenth century; Galileo and Kepler in astronomy, Gilbert in electricity, and Harvey in physiology made great contributions to scientific knowledge. Francis Bacon, nobleman, politician, and lawyer, while himself not practiced in experimental methods and while ignorant apparently of the great work of his contemporaries, had a wonderful gift in his trenchant pen and his facility of expression; and he carried the popular imagination with him in his emphasis on observation and experiment as against blind acceptance in the written word. The following passage accredited to him illustrates admirably the irony and sarcasm he could use to emphasize his contentions:

"In the year of our Lord 1432, there arose a grievous quarrel among the brethren over the number of teeth in the mouth of a horse. For 13 days the disputation raged without ceasing. All the ancient books and chronicles were fetched out, and wonderful and ponderous erudition, such as was never before heard of in this region, was made manifest. At the beginning of the fourteenth day, a youthful friar of goodly bearing asked his learned superiors for permission to add a word, and straightway, to the wonderment of the disputants, whose deep wisdom he sore vexed, he beseeched them to unbend in a manner coarse and unheard of, and to look in the open mouth of a horse and find answer to their questionings. At this, their dignity being grievously hurt, they waxed exceedingly wroth; and, joining in a mighty uproar, they flew upon him and smote him hip and thigh, and cast him out forthwith. For, said they, surely Satan hath tempted this bold neophyte to declare unholy and unheard-of ways of finding truth contrary to all the teachings of the fathers. After many days more of grievous strife the

dove of peace sat on the assembly, and they as one man, declaring the problem to be an everlasting mystery because of a grievous dearth of historical and theological evidence thereof, so ordered the same writ down."

Bacon put exclusive emphasis upon the inductive method, that is, direct observation of natural and inferences drawn therefrom as against the written words of the past.

In the year of Bacon's death, 1626, a Frenchman who some years before had left the army because of his interest in philosophy, returned to Paris to begin the definite study of mathematics as the basis of a system of philosophy; and 11 years afterward Descartes published a system of coördinate geometry which for the first time linked together the old mathematical sciences of geometry and algebra. In Descartes' philosophy of science, he emphasized the development of theories obtained intuitively and the deduction of conclusions from those theories.

For many years the 2 methods—the inductive method of Bacon based upon pure experiment, and the deductive method of Descartes based upon intuitive reasoning—have found themselves opposed to each other. Even today it is common for philosophers to discuss the relative value of inductive and deductive methods, but it seems to me that such discussion is like an argument as to which part of the body is most important to a man: Does he need most his head, his heart, or his intestinal tract? The answer is, of course, that he needs them all; he cannot live without them. To find out something about nature, we need facts first of all, and second, a linking idea that will enable us to get into one picture all the facts we are considering. This linking idea we call a hypothesis. Then, from the hypothesis we deduce consequences; these consequences must follow from the hypothesis and they must also be of the type we can verify. It is of no use to deduce consequences that are impossible for us to verify when we are searching for evidence as to the validity of a hypothesis. If all the consequences we can deduce and all the facts we can find fit the picture we form, then we term that picture a theory and grant it validity until we meet well attested facts that will not fit it.

The fundamental purpose of scientific research is to make an orderly picture of nature, so that we can understand it and thus be able to predict for ourselves without actually determining all the facts.

It may be seen that the scientific method involves both the inductive method of Bacon and deductive method of Descartes. Bacon laid the greater stress on the experimental work leading to the facts that a hypothesis was formed to fit. Descartes laid the greater stress upon the intellectual leap by which a hypothesis was invented to fit the facts, but both are necessary. We must get the facts by experiment, and we must deduce a hypothesis by instinct. A great experimenter perhaps will accumulate many facts before finding a fitting hypothesis. A great thinker may leap intuitively at a hypothesis before he has many facts. In one case, the experimenter must search for his hypothesis; in the other, the thinker must find an experimenter to supply him with the facts. Sometimes the completed theory must be abandoned entirely because facts are found that are quite incompatible with the theory, so that it is necessary to construct an entirely new picture; at other times, and perhaps more generally, a theory may have to be modified or extended in detail as new facts become available.

The fundamental purpose of scientific research is to make an orderly picture of nature, so that we can understand it and thus be able to predict for ourselves without actually determining all the facts directly.

The following is perhaps a rough picture of the way in which man has proceeded in his conquest of nature. Suppose that a man entered the door of a vast room which was a storehouse of information—a library, in fact; but suppose that instead of books each fact or statement was written on a piece of paper and that these pieces of paper, of all sizes and kinds and written in all languages, were piled up higgledy-piggledy so as to reach to the ceiling; and, moreover, suppose that the room was unlimited in extent: The first impulse of a man entering such a room would be to go away, but the man I am speaking of is the human race, and the difference between the human race and other animals is that it did not go away; it set to work to sort the facts. Very, very slowly at first, but faster later as it gained experience, the human race started to sort out that library of facts and to place together the facts that seemed to be of the same kind so that they could be classified. At first, when man took up the slip of paper and read it, it meant nothing to him because he had never seen the same fact before, and so he put it down and went on to the next; but presently he began to find that many slips had the same or similar facts on them and he began to put them together and regard them as in the same classification or, as he put it, due to the same cause. Quite often man was wrong in this belief and his association of facts proved later to be incorrect; such incorrect associations have persisted through the ages. When such incorrect associations have been held by many men for many years, we call them superstitions, and they become so rooted in our minds that they are very hard to eradicate. Perhaps the most interesting systems of incorrect associations of facts are those known as *magic* and *religion*

One of the earliest facts of which an animal becomes conscious is that its own body is not functioning normally. Usually the trouble corrects itself and the animal recovers. As soon as man began to reason, he must have tried to find remedies for his bodily disorders, and those remedies would be associated with his daily routine and especially perhaps with food. If a plant can make you ill, cannot the same plant or another make you well? When primitive man ate the same plant, he was using a homeopathic medicine; when a different plant, an allopathic medicine. When he simply hung the plant around his neck, he was employing magic. Among primitive peoples, magic always has played a great part, and it is perhaps a little difficult for us to

realize how deeply the principles of magic are entrenched in the thought and history of man.

Frazer analyzes into 2 the principles on which magic is base: first, that like produces like or that an effect resembles its cause; and, second, that things which once have been in contact with each other continue to act on each other at a distance. From the first of these principles, which he calls the "law of similarity," is inferred that a man can produce any effect he desires merely by imitating it, so that if a savage, for instance, wants a good crop, he will take care to have it sown by a woman who has many children; or if a witch doctor wants to hurt a man, he will make an image of him and then destroy it in the belief that just as the image suffers, so does the man, and when it perishes, he must die. From the second principle, it is inferred that whatever is done to a material object will affect any person with whom the object was once in contact, so that most savages are very careful to burn any hair they cut off or the parings of their nails lest an enemy might use them to do them harm; and in some African tribes, anything once touched by the king must be carefully destroyed.

The negative principle corresponding to the principle of similarity is the great widespread law of taboo which governs the things a man abstains from doing lest, on the principle that like produces like, they should spoil his luck. The Eskimo boys, for instance, are forbidden to play cat's cradle because if they do so, their fingers in later life might become tangled in the harpoon line. The principles of magic are so widespread that almost all the lives of primitive peoples have some relation either toward acts intended to produce luck or toward things refrained from lest they produce ill luck. These widespread roots are by no means extinct among us today, so that on careful analysis many of our beliefs will be found to be essentially magical in origin although generally we are no longer conscious of the sources from which those beliefs have sprung.

An even greater factor than magic in the history of man has been the development of religion. Very early man observed that his food and well-being were connected closely with natural phenomena, such as the cycle of the seasons, which we know to be due to the movement of the earth around the sun. He, however, catalogued the facts that he knew under the hypothesis that natural phenomena were due to the operation of intelligent beings made in his image, and gave these invented beings jurisdiction over groups of natural phenomena so that there were gods of the earth, the sky, the sea, and minor gods of trees, rivers, and mountains. Sometimes psychological facts were classified in the same way, and there were gods of love and war, or terror and sorrow; and thus was built up the structure of religion. When the great prophets came, Buddha, Jesus, and Mohammed, their philosophy drew on this structure and their followers incorporated much of the earlier religious belief in the systems of philosophy that were founded on their teachings; thus today in the vast mass of what we term religious beliefs we come continually on groups of associations that started as hypotheses to be used in the classification of natural phenomena. Many Christian hymns still repeat the belief that the crash of sound following the discharge of electricity from a cloud is the voice of a god.

Unquestionably, the development of magic and religion as pseudosciences, which provided a systematic classification of phenomena, tended to retard the development of scientific thought; but this probably was not so much because the classifications they provided were incorrect as because of their attitude toward the method by which such classifications should be made. From the beginning, the insistent note was heard from priests and prophets that it was the duty of their followers to have faith, to accept, and to follow authority.

The acceptance of authority is the very antithesis of the scientific method of thought. Step by step, man has established his claim to deal with phenomena directly, without the acceptance of any authority; but signs are not lacking that today this claim is being challenged, and challenged sharply.

Now, the acceptance of authority is the very antithesis of the scientific method of thought. Step by step, man has established his claim to deal with phenomena directly, without the acceptance of any authority; but signs are not lacking that today this claim is being challenged, and challenged sharply. The troubled time through which we are passing has enabled men to seize authority who have no desire that independent decisions shall be made by those whom they rule, and who believe (in most cases sincerely) that rule by authority is necessary. In Italy, in Germany, in Russia today authority is the only voice to be heard. It may appear that this has no relation to technical science, that the suppression of adverse political opinions has no importance for the future of engineering; but science is all one, its method and its spirit are one, and the age-old foe of that method and that spirit is authority.

Certain characteristics of scientific thought distinguished it very sharply from many other methods of thought. I have already dealt with its neglect of authority as such and with its direct appeal to experiment and to the classification of demonstrated facts; but in the political sphere, and I am afraid in the sphere of sociology and economics, the absence of emotion, which is characteristic of scientific thought, is an even more striking distinction. In most political matters we do not think, we feel. Some years ago I reminded a friend of mine who was praising a certain national statesman that though he might be, as my friend claimed, the wisest and noblest of mankind, he yet was a man and not a god; and when a few years later my friend had changed his political views, I had to remind him that that statesman might be the vilest and basest of mankind, but he was a man and not a devil.

The following quotation from Bertrand Russell's "Skeptical Essays" seems to me to express better than I could the difference in methods of thought:

"We have had in recent years a brilliant example of the scientific temper of mind in the theory of relativity and its inception by the

world. Einstein, a German-Swiss-Jew pacifist, was appointed to a research professorship by the German Government in the early days of the war; his predictions were verified by an English expedition which observed the eclipse of 1919, very soon after the Armistice. His theory upsets the whole theoretical framework of traditional physics; it is almost as damaging to orthodox dynamics as Darwin was to Genesis. Yet physicists everywhere have shown complete readiness to accept his theory as soon as it appeared that the evidence was in its favor. But none of them, least of all Einstein himself, would claim that he had said the last word. He has not built a monument of infallible dogma to stand for all time. There are difficulties he cannot solve; his doctrines will have to be modified in their turn as they have modified Newton's. This critical undogmatic receptiveness is the true attitude of science.

No engineer will object to better planning; but it is essential that before we adopt a new system of industry on a nation wide scale, we should have reason to believe that it is a better system.

"What would have happened if Einstein had advanced something equally new in the sphere of religion or politics? English people would have found elements of Prussianism in his theory; anti-Semites would have regarded it as a Zionist plot; nationalists in all countries would have found it, tainted it with lily-livered pacificism, and proclaimed it a mere dodge for escaping military service."

In the brilliantly written introduction to that book, Russell points out that the amount of emotion felt by any thinker upon a subject is a measure of the uncertainty he has with regard to that subject. A denial that the logarithm of 2 is 0.30103 arouses absolutely no anger in any breast. When, as is reported probably without truth, a legislature ordered that the ratio of the circumference of a circle to its diameter shall be considered for convenience as equal to 3, or when a statesman states in a court of law that he doesn't believe that man is a mammal, no sense of indignation arises; it is the risible faculties only that are stirred. However, when we become less certain, we become more emotional. An attack on one's personal character easily may stir us to anger because of internal doubts as to whether that character is unassailable, while the wild enthusiasm with which a nation will undertake to destroy that nation is a measure of the complete ignorance that exists as to the nature of the matter at issue. It is very unfortunate that in recent discussions of social reconstruction and of economics a large amount of emotion has entered, so that it becomes of greater importance to consider the attitude of the Russian government toward religion or toward marriage than to study dispassionately the possible success of the gigantic economic and social experiment in which they are engaged; or to criticize the relations of statesmen to certain bankers who stand as symbols, than to discuss whether or not their views on finance relate to facts.

We are told often nowadays that our economic system has failed and that the individualistic control of production and distribution must be replaced by another more centralized system. No engineer will object to better planning; but it is essential that, before we adopt a new system of industry on a nationwide scale, we should have reason to believe that it is a better system. Now, the atmosphere in which the existing discussion of economics and sociology is being carried on is singularly unsuitable for such a discussion. There is a story of a preacher who lost his place in his sermon when Henry Ward Beecher was in the congregation. He afterward asked his distinguished colleague what he did when he found himself in a similar difficulty. "Oh," said Beecher, "I do what you did; I yell." At the present time many of the lesser bureaucrats and politicians seem to meet difficulties by yelling. Against this spirit it is the duty of those who have had the advantage of a scientific training to set their faces sternly.

Unfortunately, so long as men's actions are controlled by their emotions, an objective thinker who discussed every proposition without emotion would have no part in modern political life, since a politician must understand the effect of emotional thought and must be prepared to utilize emotional appeal if he is to obtain popular support. A successful political leader must tend therefore either to believe his own emotional appeal or to become a cynic and to some extent a hypocrite if he exerts that appeal without belief. It is this difficulty that makes even the greatest democratic leaders seem insincere in many of their actions; the appeal to emotion is unavoidable if popular sanction is to be obtained, and yet their critics and often they themselves in retrospect feel that appeal to be false and unwarranted. It seems to me that for this reason alone the political arena is unsuitable for the scientific man and that those who believe most fully in the value of the scientific spirit should be prepared to understand and sympathize with leaders who must obtain general popular approval for their actions.

The cleavage in intellectual outlook and mental habits between the political leader and the scientist, the engineer, or, for that matter, the industrialist, is a very real and fundamental one and by no means is to be dismissed summarily. It is common for scientists and industrialists to discuss the methods of the politician as if they were either merely stupid or deliberately wicked, while the views of the political expert as to the "intellectuals" are often scornful in the extreme. In practice, the adoption of political methods controlled by pure reason could succeed only if they involved a dictatorship and the rule of the majority of the people by a small minority. For this reason, the modern dictatorships, whether fascist or communist, can be far more objective and direct in their methods than can democracies. This does not mean that dictators are necessarily, or even probably, exponents of the scientific spirit—indeed, their constant appeal to *ex-cathedra* authority is essentially unscientific; but it does mean that the leaders of a democracy cannot be truly scientific in their attitude and that scientific men must choose between the path of pure reason, which leads directly to oligarchy, and democracy, which involves a certain amount of compromise and confusions.

Leaders of a democracy cannot be truly scientific in their attitude and scientific men must choose between the path of pure reason, which leads directly to oligarchy, and democracy, which involves a certain amount of compromise and confusions.

In 1916, Doctor Steinmetz published a brief paper entitled "Industrial Efficiency and Political Waste" (*Harpers Magazine*, v. 133, 1916, p. 925) in which he warned of the necessity for a change in the political system, taking as a model the efficiency of great industrial organizations. This change he felt was necessary because "The economic development of the world, accelerated by the World War, has made a coöperative industrial organization of our nation a necessity for self-preservation. Such a coöperative industrial organization," said Steinmetz, "presupposes a powerful, centralized government of competent men remaining continuously in office." Doctor Steinmetz felt that such a political change, however desirable, was unlikely to occur since it was incompatible with the democratic temperament of the American people.

If the democratic system of government cannot change to meet the requirements of the changing world system, it must give way inevitably to other systems. That this is so is the claim of many leaders of political thought and, notably, of Mussolini. Only a few years ago, however, it seemed impossible that industry ever should be organized to use scientific methods. The industries of the last century were, with few exceptions, utterly remote from the methods of thought current in the laboratories of the universities, and were controlled largely by "self-made" autocrats. Within our lifetimes all that has changed and the leaders of our modern industries are often technically trained experts, completely removed from their predecessors as to their outlooks and habits of thought.

In order to attain a similar result in the field of politics, we need no revolution; we require only an orderly evolution of the same type. As Janssen says, "There are very few difficulties which cannot be surmounted by a will strong enough or by study sufficiently profound." It is not at all impossible that in a few years the political demagogue may be as rare as the industrial autocrat has become. In order to achieve this result, we must improve the methods of thinking of the public so that they will select suitable governors and then will require from them real leadership and accurate thought. It is both our duty and our right to select for ourselves those who govern us, and the necessary changes can be effected by the proper exercise of that duty and right. The art of government is exceedingly difficult, and it is of the utmost importance, especially in such times of transition as the present, that the men chosen as administrators should be selected with the utmost care.

If the democratic system of government cannot change to meet the requirements of the changing world system, it must give way inevitably to other systems.

The selection of the best methods of procedure in government, as in science, depends eventually upon judgment; and judgment depends upon the natural capacity of the judge and of his training and experience. It should be accepted that in any judgment there will be error and that errors will occur in accordance with the laws of probability. The judgment will be better as the probable error is smaller, but there always will be some error. The administrator, moreover, will suffer from bias. If he is sufficiently objective in mind and sufficiently experienced, he will recognize that and will attempt to make a correction for it just as we correct precision measurements for the "personal equation." Therefore, we should so select our methods of government that there is a maximum chance of arriving at the best judgment, a minimum opportunity for bias, and a probability that the best judgment that can be arrived at will be applied.

Let us accept and consider all proposals, of whatever kind, for a better method of operation; let us refuse absolutely to accept authority as such; let us ignore emotional appeals; and let us pin our faith to those methods of reasoning that have proved so successful in the analyses of all types of natural phenomena.

In so far as our present methods do not meet these requirements, they should be changed, but the most important matter is that we must be prepared to seek out specifically for the functions of government the best men that we have, not necessarily the best in quality, but often the best in character, since a man might have first class judgment and yet be so biased by his ambitions that his decisions would be affected.

In addition to selecting the most suitable leaders, however, the public must be willing to accept their leadership, to value the expression of intelligent thought, and to discount all appeals to emotion and to sectional interests.

In order to attain this result, it is the duty of scientific men everywhere to insist on the value of the scientific spirit and method of thought. My plea today, therefore, is that we deal with the problems of social reconstruction as we do with all other problems. Let us accept and consider all proposals, of whatever kind, for a better method of operation; let us refuse absolutely to accept authority as such; let us ignore emotional appeals; and let us pin our faith to those methods of reasoning that have proved so successful in the analyses of all types of natural phenomena.

The scientific method of thought is not applicable to only one class of phenomenon nor is its use confined in any way to those who have been specifically trained in technical science. The scientific habit of mind and the scientific methods should be understood and cultivated by the community as a whole.

I think that all of us must desire that we honestly could say of ourselves, as Francis Bacon felt justified in saying:

> "For myself I found that I was fitted for nothing so well as for the study of Truth; as having a mind nimble and versatile enough to catch the resemblance of things (which is the chief point) and at the same time steady enough to fix and distinguish their subtler differences; as being gifted by nature with desire to seek, patience to doubt, fondness to meditate, slowness to assert, readiness to reconsider, carefulness to dispose and set in order; and as being a man that neither affects what is new nor admires what is old, and that hates every kind of imposture. So I thought my nature had a kind of familiarity and relationship with Truth."

Electric Discharges in Gases—II

Ions in Dense Gases

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LIKE CAESAR'S GAUL, the vast domain of electrical phenomena in gases may be divided conveniently into 3 parts. Of these the wildest and the hardest to penetrate by far is that of the self-sustaining discharges, the various forms of arc and glow and spark. In these the gas is swarming with free electrons and ionized atoms and excited neutral atoms and corpuscles of light, appearing and disappearing and changing state and interacting with one another and with the electrodes and the walls of the containing tube in such a tumultuous variety of ways that the phenomena are very difficult to understand. At the other extreme is the best ordered of the 3 divisions, comprising the experiments in which beams of free electrons or ionized atoms or photons are carefully produced so as to consist of particles of a single kind with a single energy and a single velocity, and are admitted into tubes of gas so rarefied that the encounters of individual particles with individual atoms can be studied. These are the provinces of the other two articles of this series, written respectively by Dr. Joseph Slepian and R. C. Mason (scheduled for the April issue of ELECTRICAL ENGINEERING) and by Dr. Tonks (February issue). In this article I take the intermediate division, comprising the experiments in which ions of various kinds are produced in intelligible ways and then are set to wandering through "dense" gases—meaning by this, gases so dense that an ion cannot traverse the experimental tube, or pass from one to another electrode thereof, without making hundreds or thousands of collisions with atoms.

This article is a review of some of the established facts and accepted theories pertaining to the behavior of ions in dense gases, supplementing the article that appeared in last month's issue reviewing current knowledge concerning ionization and excitation, and preparing the way for next month's article which will discuss various types of electric discharges in the light of the basic processes set forth in this and the preceding article. This is the fourth of a series of special articles developed under the sponsorship of the A.I.E.E. committee on education, and the second of three devoted to the major divisions of the general subject of electric discharges in gases. Full details concerning this series of articles are given on p. 238 of ELECTRICAL ENGINEERING for February 1934. —Editor.

Drifting of Electrons Through a Gas Pervaded by a Field: Theory

Let us form a mental picture of a simple scheme of apparatus: a pair of parallel plates, "cathode" and "anode," the former pouring out a quantity of electrons which are drawn by a field, of uniform strength E throughout the interspace, to the latter. The cathode plays the part of the hot filament so frequently figuring in experiments on gases of low density. It may be a heated plate, or a slab of cold metal from which electrons are elicited by ultraviolet light; or it may be a metal wall with a hole or holes, through which electrons wander from some source behind it into the interspace between it and the anode. If the distance between the plates is of the order of centimeters, the pressure of the gas (supposing it to be near room temperature) should be hundreds of baryes at least.

The electrons emerge from the cathode with relatively small speeds; the field picks them up at once, and accelerates them. Before they have gone more than a small fraction of the way toward the anode, they collide with atoms, or with molecules if the gas is a molecular gas such as air. In order not to have to say "atoms or molecules" constantly, I will henceforth use "atom" to stand for either. *In their collisions with atoms the electrons suffer losses of speed which are small, but deflections which are great.* Consequently, when they have receded far enough from the cathode to have experienced a few collisions apiece, they have nearly as much kinetic energy as though they had fallen unchecked through the field to the place which they have reached, but instead of following the lines of force they are darting about in every direction like particles of a gas. The atoms have converted what in a vacuum would be a rain of electrons, falling in nearly straight lines from cathode to anode, into a chaos of random flights. *The gas composed of neutral atoms is now mingled with an electron-gas.*

We now make 2 specific assumptions, for convenience rather than for necessity: (a) that the collisions between electrons and atoms are strictly elastic, and (b) that the average angle of deflection suffered by an electron at a collision is 90 deg. To ensure the validity of the former, we must keep the field strength in the experiment so low that no electron ever acquires enough energy to ionize or excite an atom (see "Electric Discharges in Gases—Ionization and Excitation," by Dr. Tonks, p. 239–43, ELECTRICAL ENGINEERING, February 1933); this is not a severe limitation, as we can produce many important phenomena while obeying it. In an elastic collision, the electron transfers to the atom a fraction—call it

ϵK—of its kinetic energy K which is indeed small, ϵ being less than $4m/M$; here m and M stand for the masses of electron and atom, respectively, and M is always thousands of times as great as m.[1] The second assumption we know to be sometimes incorrect, for physicists are now making immediate observations of the deflections of electrons by atoms, experimenting with the technique in which an electron beam is sent across an extremely rarefied gas. Before long, people will begin to undertake the task of modifying assumption (b), but for the present it satisfies much better than one might perhaps expect, and it will always be the simplest picture of the fundamental doctrine, that the motion of electrons through a gas is an alternation of sudden impacts with unimpeded flights.

From these assumptions it follows, as I said before, that when the electrons have gone a little way from the cathode their speeds are nearly the same as though they had fallen unchecked through the field, but their directions of flight are random. As the electrons continue onward through the material gas, accelerated constantly by the field and impinging on atom after atom, the first of these conclusions becomes untrue. This is because of the fact that the energy loss at a collision is proportional to the kinetic energy of the electron. Eventually—that is to say, far enough out in the gas—the mean kinetic energy $\bar{K}$ of the electrons becomes so great that the average loss at collisions (we put it at half the maximum loss, $2(m/M)\bar{K}$) balances the average gain from the field during the free flights between the collisions. It is as though at every impact a tax were levied upon the electrons, proportional to the capital which they have already amassed; this increases steadily as they enrich themselves, until it swallows up their fixed income. Thus beyond a certain distance from the cathode there exists a close approximation to the so-called "terminal" condition, in which the mean kinetic energy $\bar{K}$ of the electron-gas does not vary from place to place, but has a constant value depending upon the field strength. Nearly all experiments are performed in tubes so proportioned and filled with gas of such density, that practically this terminal condition prevails throughout the region of the observations; and we shall consider it henceforth as so prevailing.

One other and most important aspect of this electron-gas remains to be considered. Each of the "free paths" of an electron from one impact to the next, being performed in the applied electric field, is bent or swerved by that field; though the *initial* directions of the free paths may be distributed isotropically or quite at random, their *final* directions will depart by a little from the isotropic distribution, tending to favor the direction of the field. It may be shown that the net effect is the same as though the electron gas were steadily drifting through the material gas with a constant "drift speed," superposed on isotropic zigzag motions of its particles. The drift speed is very much smaller than the average speed of these random motions, and the drifting electron gas may be likened to a wind or a moving cloud, things which also move with a mass-motion much slower than the random motions of the molecules or atoms which compose them. This drift speed is one of the most frequently measured quantities in this department of physics. I denote it by u; the mean speed of the random motions of the electrons by ω; the mean kinetic energy of the electrons by $\bar{K}$; the mean free path of the electrons by l; the mean free time or average interval between successive collisions (of an electron with atoms) by τ; the field strength by E; and quote the customary formulas.

The formula for u is this:

$$u = \frac{1}{2}(eE/m)\tau = \frac{1}{2}eEl/m\omega \tag{1}$$

One may derive it by considering that, during the mean free time, an electron is always experiencing the acceleration eE/m (e = charge, m = mass of the electron) in the applied field; that, as a result, its speed in the field-direction is on the average greater by $(eE/m)\tau$ at the end than at the beginning of its free path; that this comes to the same as saying that its *average* speed along the field-direction during its free time is greater by $\frac{1}{2}(eE/m)\tau$ than it would be if there were no field; and finally, that this average excess speed which has just been evaluated is entirely responsible for the drift, and is in fact the drift-speed, because if there were no field there would be no drift at all.

The formula for $\bar{K}$ is this:

$$\bar{K} = \sqrt{M/8m}(eEl) \tag{2}$$

M standing for the mass of an atom of the gas. One may derive it by considering that the kinetic energy which an electron acquires from the field during its free flight is on the average[2] $\frac{1}{2}m(eE/m)^2\tau^2$; that the kinetic energy which an electron loses at an impact against an atom is on the average $2(m/M)\bar{K}$, as mentioned above; and that in the terminal condition these two quantities are equal. It is also assumed that $\bar{K}$ is equal to $\frac{1}{2}m\omega^2$, and here the reader may well object that this amounts to identifying the mean speed and the square-root-of-mean-square speed of the electrons, which certainly is wrong. There are other examples of impeachable averaging in the arguments leading to eq 1 and eq 2, but it is not worth while to make an elaborate attempt to better them, for even if we could make them unassailable (which we could not) there would still be the uncertainties of assumptions (a) and (b). It is best to consider that the right-hand members of eq 1 and eq 2 are both to be multiplied by unknown factors, which we have

1. If the reader is willing to assume that a central impact is the most efficient in transferring energy, he may simply suppose that the electron approaches along the x-axis with speed u, and the electron and the atom depart along the same axis with speeds u' and U', respectively; the result is then obtained by solving for (U'/u) the two equations of conservation-of-momentum ($mu = mu' + MU'$) and conservation of kinetic energy ($mu^2 = mu'^2 + MU'^2$). It is assumed that the atom is initially stationary, an assumption nearly always acceptable because electrons (owing to their lesser mass) are usually moving much faster than atoms.

2. This is not so obvious as it may seem. An electron which starts with speed v on a free path inclined at angle θ to the field-direction possesses, at the start, kinetic energy equal to $\frac{1}{2}mv^2$; at the end of time t the kinetic energy has increased to $\frac{1}{2}m(v^2 + 2atv.\cos\theta + a^2t^2)$, where a stands for (eE/m). The second term however vanishes in the averaging, leaving only the third to express the mean increment of kinetic energy.

fairly strong grounds for believing not very different from unity—between $\frac{1}{2}$ and 2, quite probably. (In eq 1 this factor often is assigned the value 1.63.)

Eliminating l between (1) and (2) we obtain the relation:

$$\bar{K}/u^2 = M \tag{3}$$

an equation convenient for experimental test.

It often is desirable to speak of the temperature T of the electron gas, or simply the "electron temperature"; this quantity is equal to the mean kinetic energy $\bar{K}$ multiplied by a universal constant; the relation between $\bar{K}$ in ergs and T in degrees is the following:

$$\bar{K} = \frac{3}{2}kT \tag{4}$$

where k is the "Boltzmann constant," equal to $1.37 \cdot 10^{-16}$. Putting T into eq 2, one notices that the temperature of the electron gas, far from being equated to the temperature—T_0, say—of the atom gas with which the electrons are mixed, is equated to an expression which does not involve T_0 at all. Indeed eq 2 shows that, under customary conditions of field strength and pressure, the field should maintain the electron gas at temperatures many times higher than T_0. This striking consequence of the theory is fully verified by experiment, as we shall see.

Diffusion of Electrons Through Gases: Theory

There is a very important theorem that a gas with a nonuniform density tends to flow or drift along the direction of its density gradient, with a drift speed proportional to that gradient. This theorem is applicable to electron gas; and we may say that a density gradient, or "concentration gradient" as it is more commonly called, is equivalent to a field—that is, to the field strength that would produce the same drift. It may be shown[3] that a concentration gradient G—to be written as dn/dz, n standing for the concentration or the number of electrons per unit volume—and the equivalent field strength E are linked by the equation:

$$E = kTG/ne = (kT/ne)(dn/dz) \tag{5}$$

It will be seen that this relation makes it possible to measure the electron temperature and so verify the striking consequence aforesaid of the theory:

Drift and Diffusion of Ions of Atomic Mass: Theory

Not all of the ions to be found in conducting gases are free electrons. All of the positively charged ions are, at the least, individual atoms which have become ionized through the loss of one electron (or more than one); they may be clusters of several atoms, one of

3. Many readers will remember the theorem that in a fluid exposed to gravity, equilibrium prevails when the pressure-gradient dp/dz is equal to the force exerted on unit volume of the fluid by gravity. If the fluid is a perfect gas, the pressure p is equal to nkT (n = number of atoms per unit volume, T = temperature, k = Boltzmann constant), and hence the pressure-gradient is equal to the concentration gradient multiplied by kT. The force per unit volume exerted by gravity is nmg, and this, when we go over to the case of an electron gas subjected to a field strength E (gravity being negligible by comparison) is replaced by neE.

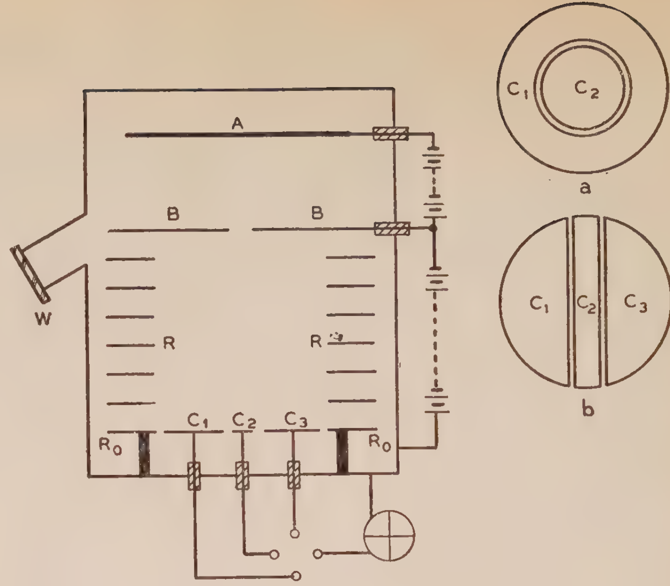


Fig. 1. Scheme for observing drift speed and diffusion conjointly

The ions drift in a uniform field directed from A toward C_1 and C_2 (sketched above "a") and after passing through the hole in B the ion stream widens laterally by diffusion. (The arrangement "b" of the electrodes serves for measuring drift speed separately, a magnetic field being applied.) (Townsend)

which is ionized. Some or all of the negative ions may be atoms or clusters of atoms to which an extra electron has attached itself.

Ions such as these will form an "ion gas" mixed with the atom gas, having (when a field prevails) a temperature and a drift speed. There are, however, notable differences from the electron gas above described. In the electric field, the electron gas of the previous case is raised to a much higher temperature than the atom gas, and this is essentially because an electron gives up so small a fraction of its kinetic energy to an atom at an impact—the energy-transfers between electrons and atoms are, we may say, very inefficient because of the great disparity of masses. In the present case the masses of atom and ion are equal, or at least of the same order of magnitude; the transfers are very efficient, and the temperature of the ion gas is practically the same as that of the atom gas. Equations 2 and 3 thus have no validity. Equation 1 retains its general appearance, with ω in the denominator of the expression for u; but now ω, like $\bar{K}$ and T, is independent of field strength, and instead of $\frac{1}{2}m$ there is a factor depending on both m_i and m_a, the masses of ion and atom, respectively. Equation 6—in which c_a and c_i stand for the square-root-of-mean-square speeds of atoms and ions, respectively, and r for the ratio m_a/m_i—is based on the assumption that atoms and ions alike behave like elastic spheres. I append to this the appropriate forms of eq 3 and eq 4:

$$u/E = 0.812(1+r)^{1/2}(el/m_a c_a) = 0.812\left(\frac{1+r}{r}\right)^{1/2}(el/m_i c_i) \tag{6}$$

$$\bar{K} = \frac{1}{2}m_i c_i^2 = \frac{1}{2}m_a c_a^2 = \frac{3}{2}kT_0 \tag{7}$$

$$E = (kT_0/ne)(dn/dz) \tag{8}$$

Return now to eq 5. It shows that if one can determine both the concentration gradient G and the field strength E which separately produce a given drift speed u, one can deduce from their ratio the electron temperature T. Since T depends on the field strength, the former measurement must be made in the presence of the same applied field as the latter; it is not, however, necessary to adjust G until the drift speed due to the concentration gradient becomes the same as that which E separately would produce, for we may make the measurement for any convenient value of G and then assume that this drift speed is proportional to G/n. Actually there is a very ingenious method in which a stream of ions is passed through a hole into a chamber of gas (Fig. 1); the stream is drawn across the gas by a field parallel (say) to the X axis, and simultaneously the ions diffuse sidewise in the YZ plane so that the stream widens steadily as it proceeds. The widening which the stream has undergone by the time it reaches the far side of the chamber is affected by the forward drift in the field and by the lateral diffusion jointly, and from an analysis of the data the electron temperature may be obtained. By a slight modification of the apparatus the drift speed due to the field may be separately measured.

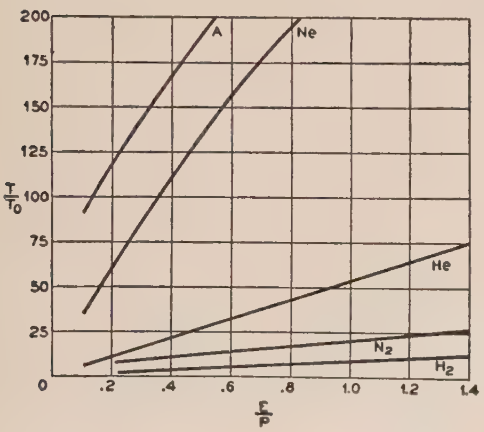


Fig. 2. Ratio T/T_0 of electron temperature to neutral gas temperature, plotted for argon, neon, helium, nitrogen, and hydrogen as a function of ratio E/p of field strength to gas pressure (Townsend)

By this procedure, values of electron temperature *200 and more times* as high as the temperature T_0 of the atom gas are observed (Fig. 2). No extravagant field strength is needed to produce such values: in pure dry argon the ratio T/T_0 is about 200 when the field strength is 0.5 volt per cm and the pressure is one millimeter of mercury. In the glowing gas which fills the tube of a mercury vapor arc, electron temperatures of 60,000 deg C or 80,000 deg C are observed (by a different method, the "Langmuir probe method," which Slepian and Mason probably will consider in their article of this series) although the vapor itself is not sufficiently hot even to soften the glass walls of the tube.

For several gases u and T have both been measured under identical conditions, this making possible a test of eq 3 and therefore of the fundamental assumption of elastic impacts. The assumption is found to be excellently confirmed for several gases, so long as T is not too great; for instance, it is verified for hydrogen, nitrogen, and helium when $\bar{K}$ is not more than 0.5 electron-volt (T about 6,000 deg C) and for argon its validity holds up as far as $\bar{K}$ = 5 electron-volts. The discrepancies which occur at higher values of $\bar{K}$ (and at low values also, in chemically active gases) may be taken as a measure of the mean departure from perfect elasticity of the impacts.

The mean free path l of the electrons may be determined from eq 1 if u and $\bar{K}$ have both been measured; or if one fully accepts both of the assumptions (a) and (b)—perfect elasticity of impacts, average deflection at a collision equal to 90 deg—one may determine l by measuring either T by itself or u by itself (using in the former case eq 2, in the latter the equation obtained by eliminating $\bar{K}$ between eq 1 and eq 2.) For some gases l is nearly constant, while for others—argon is a conspicuous example—it varies rapidly with $\bar{K}$ (Fig. 3). This puts somewhat of a strain on the otherwise convenient picture of the atoms as elastic spheres, inasmuch as it becomes necessary to imagine that the size of the sphere depends on the speed of the electron which is approaching. It is perhaps more comfortable to imagine that there is a certain chance of the electron traversing the sphere instead of rebounding from it, this chance varying rapidly with the speed of the electron. Such compromises are often necessary when one wishes to avail oneself of the advantages of a simple and pictorial model. In this case the necessity is inescapable, for these results are sustained by those of a great many experiments in which narrow streams of electrons are projected across thin strata of rarefied gases, and their mean free path is determined by measuring the number either of those which are deflected by collisions or of those which manage to cross undeflected.

Finally, suppose that on the constant applied electric field E there is superposed another at right angles to it, which second field is oscillatory (alternating); denote this latter by F *sin nt*. Experiments show that on the steady drift along the direction of the

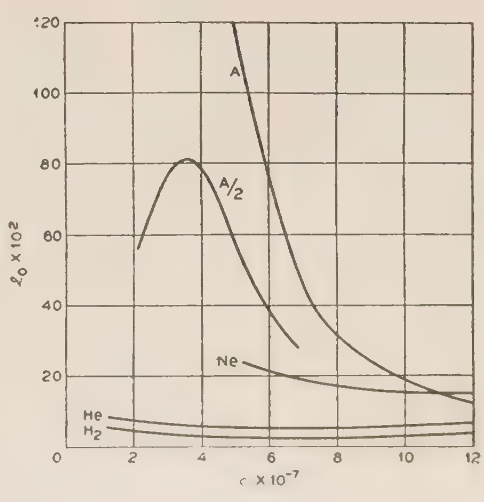


Fig. 3. Mean free path l of free electrons in argon, neon, helium, and hydrogen at a gas pressure of 1 mm of mercury, plotted as a function of c, the root-mean-square speed of the random motion of the electrons (Townsend)

constant field there is now superposed a sidewise to-and-fro motion of the electron gas; there is what may be called an "oscillating drift," in phase with the field which produces it. Up to frequencies of the order 10^6 (cycles per sec) this mass vibration of the electron gas is found to have the amplitude which is to be expected from eq 1, if for the factor multiplying E in that equation we put the value μ derived from experiments with steady fields, and assume that the sidewise drift speed is equal to $\mu F \sin nt$. In this substitution the value put for $\bar{K}$ is that corresponding

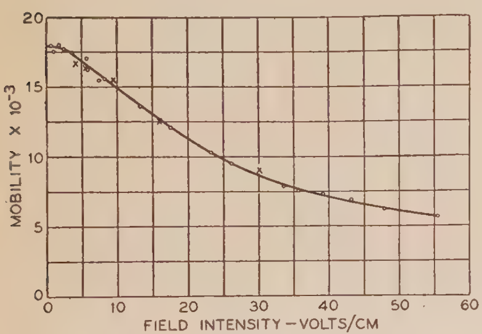


Fig. 4. Mobility of free electrons as a function of field strength, in nitrogen at atmospheric pressure (Wahlin)

Mobility means ratio of drift speed to field strength

to the steady field strength E prevailing in the experiment, the ratio of F to E being intentionally kept so small that the alternating field does not appreciably affect the electron temperature.

Diffusion and Drift of Massive Ions: Experimental

Measurements of diffusion of positive ions always show that their temperature is indistinguishable from that of the neutral gas: T is equal to T_0, as we expect from the fact that no kind of positively charged particle is known which is not a charged atom or cluster of atoms. Measurements of diffusion of negative ions usually show the same, which implies that electrons do not long remain free in ordinary gases, but quickly attach themselves to atoms or atom clusters. For electrons to remain free in a dense gas it is necessary that the gas should be inert, or at least chemically inactive, and that it should be well dried and well freed of organic vapors such as those of stopcock grease; or else that the current density or the field strength (strictly, the product of field strength by mean free path) in the gas should be large, as in the arc or just before the passage of a spark. The study of diffusion and drift of massive ions had been carried on intensively for more than 10 years before physicists began to dry and purify their gases well enough to make free electrons observable.

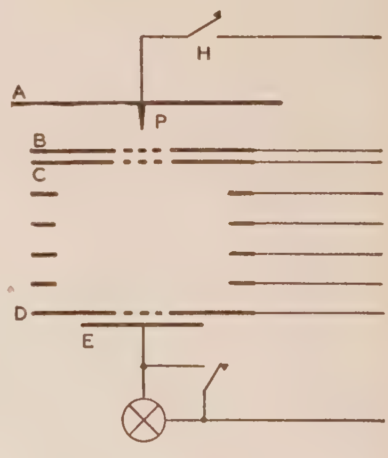
Measurements of drift of positive ions always show that drift speed is proportional to field strength, in accordance with eq 6; the same is true for negative ions, except under the aforesaid conditions where free electrons persist. The ratio u/E, evaluated for standard density of a gas (usually the density corresponding to room temperature and atmospheric pressure), is termed "mobility." The determination of mobility values was one of the most interesting, or anyhow one of the most widely studied, problems of physics during the first 20 years of this century, and is still cultivated.

The methods of measurement are legion; I will mention only a very late one (Fig. 5). A flock of ions is drawn by a field through a pair of consecutive shutters mounted a distance D apart, which are opened for brief moments separated by a time interval T; they pass to the electrometer beyond the second shutter if, and only if, their drift speed u is equal to D/T. Actually the shutters, as I have called them, are transverse electric fields which are applied by a high frequency generator, in such a way that the ions can reach the electrometer only if they traverse the distance D during an integer number of half-cycles of the frequency (5 half-cycles, in some actual instances). On plotting electrometer current against frequency, a curve is obtained with a peak for each kind of ion present, and from the location of the peak u may be evaluated. In most cases the ratio u/E lies between 1 and 10 when u is expressed in cm per sec and field strength in volts per cm.

The situation with respect to theory has been confused through nearly all of the third-of-a-century of experimental research by a remarkable fact of experience: when ions of a given sign (positive, say) originating in different gases, and therefore presumably consisting of different charged atoms, are caused to drift across some particular gas such as air, they all turn out to have the same mobility! There have been 30 years of controversy over the meaning of this singular rule: whether it signifies that the original charged atom quickly surrounds itself with a cluster of atoms picked up from the gas through which it happens to be passing (the "cluster theory") or whether it has some other cause. Only within the last 3 years have violations of this rule been observed: cases in which it appears that positive ions of a known variety (ionized atom of one of the alkali metals) drift through a gas (any one of the

Fig. 5. Scheme for measuring drift speed of ions in manner described in accompanying text

Ions drift in uniform field directed from P toward E, but when they reach the planes of the gauzes they are drawn to the wires thereof by a transverse alternating field, unless they happen to reach these planes at the moments when the alternating field is nearly zero (Van de Graaff)



noble gases) clear across the experimental chamber without losing their initial and distinctive values of drift speed. This has been achieved by intensive drying and purification of the gas, coupled with the use of the method described above, which permits of observing the drift speed in the first few ten-thou-

sandths of a second of the existence of the ion. In argon the mobilities of positive ions of sodium, potassium, rubidium, and caesium are found to vary as $(1 + r)^{1/2}$, in accordance with eq 6. The simple elastic-sphere theory is nevertheless inadequate, and it is necessary to introduce a new feature into it by postulating forces of attraction between the ions and the atoms; these may be considered as arising because the charge on an ion polarizes the neighboring atoms.

Recombination

When a gas filled with equal numbers of ions of opposite signs is left to itself the ions rapidly disappear, because positives and negatives in their wanderings through the gas meet with those of the opposite sign and combine with them into neutral particles: the process known as "recombination." The disappearance is completed much more rapidly than it would be if the ions of both signs were elastic spheres having

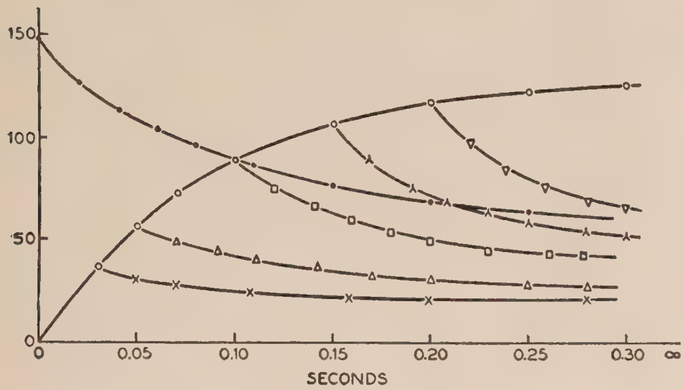


Fig. 6. Illustrating recombination

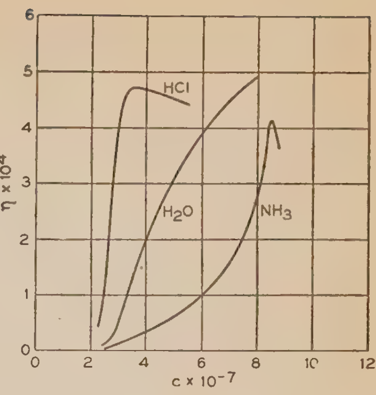
The rising curve shows the number of ions in a sample of air as function of time during a continuous exposure to ionizing rays, and the falling curves show the number as function of time after the rays are shut off. (The curve descending from the left is the fall after a 30-sec exposure.) (Schemel)

about the same radii as the atoms. This phenomenon, like the phenomena of mobility, suggests that the ions are clusters of atoms, or that they exert on one another forces which at close distances are even greater than the electrostatic attractions between them. The rate of disappearance depends in peculiar ways on temperature and pressure, and this possibly signifies that 2 ions of opposite sign must give away some of their kinetic energy in collisions with atoms shortly before they combine with each other, as otherwise they are likely to rebound from one another without combining. There are, however, many ill-understood phenomena in this field.

Attachment

The massive negative ions mentioned in the 2 preceding sections come into being because free electrons are captured by, or "attach" themselves to, neutral molecules or atoms. If a stream of free electrons drifts across a dense gas, some of its individuals are captured *en route*. Say that the gas is at pressure

Fig. 7. Probability of attachment of electrons to molecules (see text) in hydrogen chloride, water vapor, and ammonia as function of root - mean - square speed c of the random motion of the electrons. (Bailey and Ducanson)



p, and is bounded by screens at $x = 0$ and $x = L$, and pervaded by a field of field strength E directed parallel to the x-axis; then if N_0 electrons emerge per unit time from the first screen and drift across the gas, the number which arrive at the second screen per unit time as *free uncaptured electrons* may be written as $N_0 \, exp(-aL)$. The coefficient a is a sort of a measure of the tendency of the gas to capture the electrons; it depends on the electron temperature T, and therefore on E and p which control T. A better measure is the ratio of a to the number of collisions which an electron makes in going from $x = 0$ to $x = L$ if it escapes capture all the way. This may be termed "probability of attachment at a collision of an electron with an atom" though this usage is rather loose and should be analyzed carefully by any one making a study of the subject. With field strengths (or rather, with values of E/p) such as have been considered up to now in this article, it is rather surprising to learn that, even in gases such as oxygen where it is difficult to maintain a supply of free negative electrons, this probability is of the order of 10^{-6}; in the noble gases it is lower than 10^{-9}. It varies with T in strange and intricate ways which have not yet been sufficiently studied.

Self-Amplified Ionization

Return now to the scheme of apparatus proposed in the second paragraph of this article, and imagine that the anode is gradually drawn back so as to vary the distance d between cathode and anode, the potential difference V between these electrodes being always so adjusted that the field strength E remains the same. Let N_0 electrons, composing a current of strength $i_0 = N_0e$, enter the gas per unit time from the cathode. We have heretofore assumed that E is so low that all collisions between electrons and atoms are elastic; in such conditions the current i will be constant and equal to i_0, whatever the value of d. If, however, the field strength (it is really the field-strength-to-pressure ratio E/p which matters, as heretofore) is sufficiently increased, it is found that *the current increases exponentially with d: extra current carriers are arising in the gas* (Fig. 8). The electrons emerging from the cathode and drifting through the gas occasionally make impacts of such violence against atoms, that these are separated into free electrons and positive ions. "Secondary" electrons thus set free are quick to attain the electron

temperature and drift speed of the primary ions, and to ionize in their turn: the exponential relation

$$i = i_0 exp(\beta_2 d) \tag{9}$$

is due to the cumulative ionizing action of primary and secondary and tertiary and all other electrons.

The coefficient β_2 in eq 9 depends on E and p. To get an idea of its order of magnitude, take the value for air when $E = 700$ volts per cm and $p = 4$ mm of mercury, which is 8.16. This implies that under such conditions a single free electron ionizes about 8 atoms as it drifts onward through a centimeter (of course it actually travels much more than a centimeter in its zigzag path, and makes an enormous number of collisions during this interval). Owing to the high value of the ratio E/p, attachment is probably rare, so that the negative ions in the gas are actually free electrons as is taken for granted in the foregoing passage. It is, however, an unfortunate fact that when the field-strength-to-pressure ratio is so high as it is in these experiments, the advent of the extra ionization impedes very greatly or precludes altogether the use of the classical methods of measuring attachment and recombination and drift speed and electron temperature, so that we remain largely ignorant of these important phenomena in just the conditions where exact knowledge of them would be of major importance.

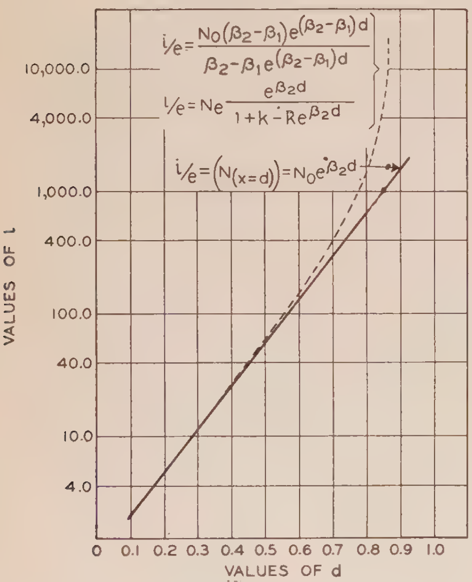


Fig. 8. Semi-logarithmic plot of current vs. electrode distance (i vs. d) in air between plane parallel electrodes

Pressure, 4 mm of mercury; field strength, 700 volts per cm. Straight line, graph of eq 9. Curve agrees with either of the annexed formulas. (Data from Townsend)

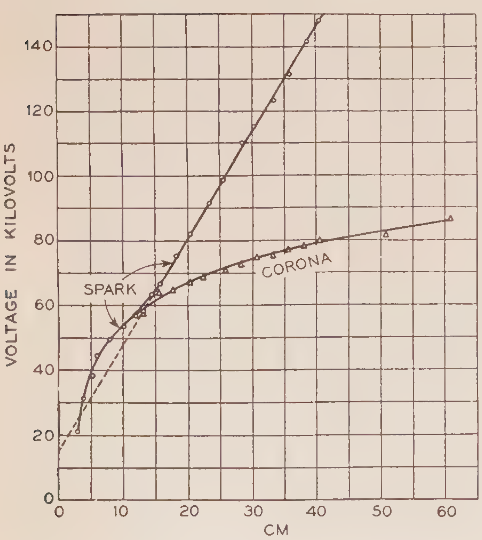


Fig. 9. Relation between breakdown potential (kv) and distance (cm) between parallel wires of 8.25-mm diameter

Beyond about 12 cm the advent of the spark is preceded by the advent of a corona discharge, and there is a range of voltages in which the latter is self-sustaining and stable. (Peek, "Dielectric Phenomena in High Voltage Engineering," McGraw-Hill)

When d is increased sufficiently, eq 9 ceases to be exactly valid, the curve rising too rapidly (Fig. 8); it appears that the current is enhanced by something additional to the ionizing power of the free electrons. When d is still further increased, something startling presently happens. With parallel plane electrodes such as have hitherto been postulated, this startling event is the occurrence of a *spark*. With cylindrical or spherical electrodes, it may be the advent of a glow or corona, a so-called "self-sustaining discharge." Paradoxical as the statement sounds, the spark itself is properly to be regarded as a self-sustaining discharge. True, it ceases almost immediately; but that is for a secondary reason having nothing to do with the phenomena in the gas: the immense current which flows in the spark has effects in the outer circuit, because of which the voltage between the electrodes quickly drops far below the steady value V which the experimenter was applying up to the moment when the spark burst across, and at its lowered value cannot maintain the discharge.

Hitherto in this article it has been tacitly assumed that the experimenter is doing 2 separate acts when he provides a steady inflow of free electrons or massive ions into the gas and when he provides a steady field with which to draw these ions onward through the gas. Thus in the experiments underlying eq 9, he usually extracts electrons from the cathode at a constant rate by directing a beam of ultraviolet light against that electrode, and this is an operation entirely separate from his other operation of keeping a steady voltage applied between anode and cathode. In a self-sustaining discharge, however, it is sufficient for him to attend to the second operation only, and maintain the voltage; the internal processes of the discharge itself attend to the other task of maintaining the outflow of primary electrons from the cathode. There is a gradual transition between these 2 extreme cases, covering the range where the discharge is not self-sustaining, but the current is greater than that computed from eq 9; for in this range the processes occurring in the gas are responsible for a part, though not the whole, of the primary electron stream.

Several ways are known in which these processes may act to produce the required result. Thus, if the electrons traversing the gas acquire energy enough to ionize its atoms, they also inevitably acquire energy enough to cause these atoms to send out ultraviolet light; now, ultraviolet light falling upon a metal ejects electrons from that metal; so that in the experiment just pictured, some of the electrons emerging from the cathode must be due not to the separate beam of light which the experimenter directs against it from outside, but to light generated by the passage of the previously ejected electrons through the gas itself. In this case one may say that the primary electrons receive energy from the field and give it to the atoms, which absorb it and subsequently reëmit it in the form of photons (corpuscles of light) which

carry it over to the cathode and there employ it in extracting fresh electrons. It may also happen that the atoms, instead of reëmitting this energy which they receive, keep it stored up within themselves until they happen to wander over to the cathode surface itself and impinge against the metal, whereupon their stored energy is taken over from them and employed to the same end. Such a thing is especially likely in certain kinds of gases, including the noble gases, of which the atoms or molecules are peculiarly able to retain their energy for long periods without emitting it in the form of light; during the retention they are said to be "metastable atoms." Likewise the positive ions formed in the gas and drawn to the cathode by the field may expel electrons from the metal when they strike it. Yet another possibility is, that the positive ions on their voyage through the gas may themselves split some of the atoms which they meet into free electrons and additional positive ions. In a mixture of gases, metastable atoms of the one may ionize atoms of the other.

It is probable that in actual cases where the current is greater than eq 9 admits, the current flow is contributing to its own support in 2 or more of these ways simultaneously. To ascertain what actually is happening in any case is a problem of research of which the importance is matched only by the difficulty. Its importance is largely due to its bearing on the phenomenon of "breakdown" (that is, the advent of the spark or other form of self-sustaining discharge); for breakdown comes about when these processes (together, it may be, with others as yet unrecognized) are acting powerfully enough to replace all the ions which go to the electrodes or otherwise disappear by an unceasingly equal supply of fresh ions. After breakdown has occurred and the self-sustaining discharge is established, these processes have the field to themselves. However the phenomena then differ extraordinarily from those of the gentle current-flows which have been the topic of this article; the differences being traceable in part to the great current densities, in part to the high field strengths which are accentuated by the presence of space charge.

References

No names have been mentioned in this article, as it is impossible to apportion credit properly in so succinct a treatment. I should mention at least that many of the experimental methods and much of the theory in this field of physics are due to J. S. Townsend, and that eq 6 is due to Langevin. Fuller accounts, with references to the original papers, may be found in the following books and articles:

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Social Aspects of the Engineering Approach

Social advantages and disadvantages of the engineering-scientific approach to civilization are discussed in this article, which includes full text of an address delivered at a meeting of the American Association for the Advancement of Science held in Boston, Mass., December 8, 1933. The engineer is urged to apply the precision of his thinking and his honesty in facing facts to the more complex situations that concern living organisms and our social life.

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I SUPPOSE you are all more or less familiar with that concept of the cyclical rhythm of civilization which has been popularized in recent years by Petrie, the Egyptologist, and Spengler, the German philosopher. According to this analysis, a civilization takes its origin in a profound, but as yet unexpressed, new attitude on the part of a virile, agricultural people toward the Universe. This profound, original feeling gives the bias to subsequent events throughout the life of the civilization. First, it manifests itself in great cathedrals and sculpture; next in painting, literature, and music, followed by science, mechanics, and wealth; and finally it manifests itself in dissolution which comes because of a lack of faith in the worthwhileness of the original attitude toward the universe and because of disgust with the material results which finally have been inspired by that attitude. According to this analysis we have now come to the late fall, the eventide of this civilization, and the coming of the engineer is like the coming of Indian summer in late October just before the cold and dreary days of winter.

Philosophical analysis of this sort, even when backed up by archeological research, can be, of course, merely suggestive; but after our experience with the World War and the depression of the past 4 years, we are led to question the American credo, based as it has been on faith in progress unlimited, derived from endless mechanical invention, improved methods of mass production, and ever-increasing profits. Without accepting either the implicit pessimism of the Spenglerian twilight philosophy or the Pollyanna optimism of the old-fashioned American "go-getter," I would ask you to examine superficially with me the contributions of science and

engineering, the dilemma thereby created, and a possible way out.

Productivity Increases Annually

For 100 years the productivity of the so-called civilized world has increased at the rate of about 3 per cent annually. Correcting for increase in population, the output *per capita* has increased at the rate of about 1 per cent annually. In the United States the rate of increase of material wealth perhaps has been a little faster than this; but everywhere there has been apparent a little slowing down during the World War, and especially since 1930. So we have, on the one hand, those people who proclaim that inevitably the predepression trend will be resumed, and those who, on the other hand, say that the time of the quantitative expansion of man's control over nature is now coming rapidly to a close.

Engineering and science, combined with the division of labor, have made it possible for an hour of man-labor on the farm to produce several times as much as it did a hundred years ago. In company with the rest of you I have marveled from time to time over the tremendous contribution of the reaper, the binder, the combine, the truck, the tractor, and the gang-plow; but inasmuch as we have come now to days of real soul-searching about all the things that we hitherto have called progress, I think it is high time for all of us to analyze these various labor saving devices a little more critically. Do they really save as much as appears on first glance?

True it is that the farmer puts in only a mere fraction of his own labor in producing wheat, as compared with 100 years ago, but what about the labor of the men who made the combines and the plows and the tractors? What of the labor of the men who transport the wheat the thousand miles to market, of the vast distributing and advertising machinery which seem to be necessary if we are to operate on the broad scale apparently required by the modern adaptations of engineering and scientific discoveries? I am inclined to think there is a real net gain, but it is a gain of a sort which easily can be lost altogether unless certain social adaptations very rapidly are perfected.

There Should Be More Time to Enjoy Life

The change from the back-breaking cradle of our forefathers to the modern combine ought to mean a tremendous release of human energy on the farm for something besides growing and harvesting a crop. The days when wheat was broadcast by hand, perhaps from a saddle horse, in retrospect seem quite romantic; but to the farmer who had to spend days at seeding-time where he now spends hours, the romance probably wore pretty thin. The grind of the harvest of years ago, the sweat of men in the field and women in the kitchen, were honorable things, and even were celebrated in song and story; but it did not leave much time for living. Engineers and scientists have given us the instruments and the methods whereby we can escape much of the grind; theoretically, there ought to be far more time for living and far more with which to enjoy life. Yet the reverse seems to be poignantly true.

The man who invented our labor saving machinery, the scientists who developed improved varieties and cultural methods, would have been bitterly disappointed had they seen how our social order was to make a mockery of their handiwork. No doubt they felt that they were directing their talents to free mankind from the fear of scarcity, from the grind of monotonous all-absorbing toil, and from the terrors of economic insecurity. Things have not worked out that way.

I do not mean to imply that there have been no gains. Of course there have been net gains, even if incommensurate with the hopes and promise of science. Plainly we must hold those gains, and add to them rapidly and extensively; but I think we can do this only if the planning of the engineer and the scientist in their own fields gives rise to comparable planning in our social world.

Productivity Could Be Doubled in 30 Years

So far as science and engineering themselves are concerned, I see no reason why the rate of expansion that characterized the "Century of Progress" should not be increased, at least for a time. While there are certain ultimate limitations in our supplies of coal, iron, petroleum, and soil fertility, it is obvious to most of us who are close to any particular phase of scientific research or technical organization that there are imminent discoveries which, when applied, will increase *per capita* output enormously. Nearly every technical man knows in his heart that from a purely scientific engineering point of view the most amazing things could be done within a relatively short period. Of course, in the world of hard fact the full effect of any revolutionary invention is not felt typically for 15 or 20 years; but I feel safe in saying that our scientists and inventors today have enough new stuff within their grasp or just around the corner so that the world 30 years hence easily could have a total productive power twice that of today.

It is almost equally possible that the total wealth-producing power of the world a generation hence will be less than it is today. The trouble, if it comes, will not be in the inability of scientists and technologists to understand and to exploit nature, but in the ability of man to understand man and to call out the best that is in him. In solving this limitation scientists and engineers all too often have been a handicap rather than a help. They have turned loose upon the world new productive power without regard to the social implications. One hundred years ago the power looms of England destroyed the cottage weaving industry, and during the early years of that impact misery strode over the countryside of England in proportion as the *nouveaux riche* gained capital to exploit their gains over the entire world. That kind of thing has been done again and again, and we have called it progress because the power of man over nature was increasing and because in the long run the common man shared in this increase. What happened to the common man in the shortrun, of course, could be of no concern to a *laissez faire* society.

Until recently, most of us, whether scientists, business men, or laborers, have looked back on the Century of Progress and called it good; but today the afflictions of Job have descended upon us and of necessity we must argue with Bildad, the Shunite, and set ourselves right with our God before we go forward into a prosperity 7 times that which we enjoyed before.

Acting perhaps in the capacity of Bildad, I would like to suggest that the very training which made possible the enormous material expansion of the past century may have made impossible to some extent the building of a just social system for the prompter and more uniform distribution of the wealth produced by the system. Most of the scientists and engineers were trained in *laissez faire*, classical economics, and in natural science based on the doctrine of the struggle for existence. They felt that competition was inherent in the very order of things, that "dog eat dog" was almost a divine command.

The power discovered by scientists and inventors was applied in the United States by a race of men who had developed a concentrated individual will power and an extraordinary thriftiness as a result of several generations of pioneer agricultural training and Protestant churchgoing. As a result, human power of high spiritual origin, but debased by the sophistication of the "devil take the hindmost" economics of the colleges, took command of the exploitation of the discoveries made by the scientists and inventors. Scientists and inventors have an intense kind of religion of their own—certain standards to which they like to be true—and as long as they could get enough money to pursue their researches, why should they care how some one else handled the social and economic power derived from these researches? Perhaps that is putting the matter unkindly, but other explanations that might be advanced are not much more flattering. Those who delved too deeply into social and economic problems got into trouble, and many of the best scientists felt that it was not good form to do things which to certain types of mentality seemed impractical and which might endanger science's financial support.

Technical Efficiency Vs. Culture

It is my observation that previous to 1933 more than $^3/_4$ of the engineers and scientists believed implicitly in the orthodox economic and social point of view. Even today I suspect that more than half of the engineers and scientists feel that the good old days soon will be back when a respectable engineer or scientist can be an orthodox standpatter without having the slightest qualm of conscience. It is so nice to feel that there are great supermen from whom directly and indirectly you draw your own sustenance, who, sitting Jove-like above us lesser mortals, make possible the free functioning of the law of supply and demand in such a way that their profits enlarge at the same rate that our research expands. Like most of you in this audience, I rather like that kind of a world, because I grew up in it: in some ways, I wish we could get back to it; but both my mind and my instinct tell me that it is impossible for any length of time. Of course, if prosperity returns within the next year or 2, it is possible for us to think that we are back in that old world again; but unless the people who make profits and direct capital allocation to different productive enterprises have seen a great light, or unless we move forward into certain highly centralized forms of industrial and governmental control, we shall sink back into our former trouble.

There ought to be more than a little hope in the fact that our engineers have demonstrated so successfully their skill in planning. In many great industries, the engineers have been able to mark out the contours of expansion and development 10 to 15 years ahead. If in the past they seemed to be guided by purely material and mechanical considerations, that doubtless has been because such considerations were necessarily the chief ones so long as we were conquering a continent. Today it is becoming increasingly evident that we must take into account the qualitative as well as the quantitative expansive aspects. This would suggest that in the engineering courses of the future, engineers should be given an opportunity really to enrich their minds with imaginative, nonmathematical studies such as philosophy, literature, metaphysics, drama, and poetry. Of course, so long as an engineer is burdened with the necessity of putting in 18 hours a day mastering calculus, mechanics, and the complex theories of electricity, he simply cannot give any effective attention to the cultural aspects of life; and if by accident an engineer, exposed to studies of this sort, should be enthused by them, he might for the time being become somewhat less effective as an engineer. We thus are exposed to a dilemma, which I would be tempted to solve by saying that probably no great harm would be done if a certain amount of technical efficiency in engineering were traded for a somewhat broader base in general culture.

Social Problems Crying for Solution

It is difficult to see how the engineer and the scientist can preserve much longer a complete isolation from the economic and social world about them. A world motivated by economic individualism has come repeatedly to the edge of the abyss, and this last time possibly came within a hair's breadth of plunging over. Yet science, all this time, has been creating another world and another civilization that simply must be motivated by some conscious social purpose, if civilization is to endure. Science and engineering will destroy themselves and the civilization of which they are a part, unless there is built up a consciousness that is as real and definite in meeting social problems as the engineer displays when he builds his bridge. The economist and the sociologist have not yet created this definite reality in their approach; can you, trained in engineering and science, help in giving this thought a definite body?

Today when the industrial nations of the world have skimmed most of the cream off the backward nations and the backward classes, and when there are no longer any challenging geographical frontiers

to be conquered, it becomes apparent that we must learn to coöperate with each other instead of joining together in the exploitation of some one else. This means the building of a social machinery as precise and powerful as an automobile engine. How extraordinary is the patient vigor of thought that enables a group of engineers to blue-print and execute a new design; and how sloppy is our economic blueprinting and execution by comparison!

It must be said in defense of the economists, however, that their problem is infinitely more difficult than that of the engineer. The economic engineer never has had any excuse to exist until recently because no one gave him any orders for blueprints. Even yet the objectives are so loosely defined, the popular will is in such a state of flux, that the designing of the economic engineer is about like that of an automotive engineer who discovers after he has completed his engine that it was to go into a tractor instead of an automobile.

A Coöperative State Not Impractical

As I have said to many farm audiences, we are children of the transition—we have left Egypt, but we have not yet arrived at the Promised Land. We are learning to put off the hard boiled language of the past, but we have not yet learned to speak the coöperative language of the future. One is as different from the other as a human being is different from an animal. There need be nothing impractical, there need be nothing foolishly idealistic about a Christian, coöperative, democratic state; but I fear it will take us as long to build a public consciousness fitted to run such a state as it is taking the Russians to build efficient factories and train their people to run them.

We know that there must be a balance between productive power and consumptive power, and that excessive profits used to expand productive power beyond consumptive power are sure to lead to a breakdown. We know that the continued insistence on heavy exports in excess of imports by a creditor nation is bound to lead to disaster. We know today that the great unemployment is in the so-called heavy industries, and that this could be remedied if faith in a profound new excitement swept the country like the railroad building boom of the early Eighties, or the automobile boom of the Twenties. This boom might take the form of totally new railroad equipment, or the popularization of new and better airplanes, or the making fashionable of winter homes and winter industries for every one in the South and a duplicate summer set in the North. In any event, whatever is done to stimulate the heavy industries, it is to be hoped that the bonds issued to pay for the stimulation will be on a long term, amortized, low-interest basis.

We know that we must have a monetary system that will bring about a better balance between debtor and creditor and between productive power and consumptive power. These things can be measured and social machines can be built to deal with them; but before success can be expected, there must run through the rank and file of the people a feeling that amounts to a profound determination to deal with social problems.

The Engineer and the Mathematics of Life

There is something about engineering that tends to lay emphasis on logical, cold, hard, lifeless facts. Nearly all engineers have suffered the common punishment resulting from the remorseless discipline of higher mathematics, physics, and mechanics. No man has to work as hard in college as the engineer. As a result, the engineer sometimes imputes a value to precise mathematical reasoning that it does not always have. There is such a thing as life, and the mathematics of life is as far beyond the calculus as the calculus is beyond arithmetic.

We can see in Mendelian genetics a complex algebra that has proved to be of some analytical use in determining the mechanism of heredity. Nevertheless, from the standpoint of producing superior plant and animal organisms, the engineering mathematical approach to life has not yet been especially successful. It seems to me that the emphasis of both engineering and science in the future must be shifted more and more toward the sympathetic understanding of the complexities of life, as contrasted with the simple, mathematical, mechanical understanding of material production.

The quantitative answers produced by the science of the past hundred years are not enough. They merely increase the speed of life without increasing the quality. Would that we had someone with the imagination of Sir Isaac Newton to develop the higher calculus of the engineering of life which is so necessary if our increased productive power is to increase total human happiness!

Have you not sometimes wondered whether this whole Century of Progress might not be just a superficial and temporary phenomenon after all? The increase of physical output in 3 generations is so extraordinary that we have tended to think that this is what man is meant for. It seems to me a terribly inadequate yardstick of civilization. A man has food, clothing, and shelter; wherein does he differ from the beasts of the field? Surely these are not the things that distinguish the civilized from the uncivilized. Food and shelter and the other necessaries in any rational order ought to go without saying. They ought to be as automatic, and as universal, in this day of technological achievement, as the air we breathe. It is from this point on that life begins.

Engineers! Apply Yourselves to Social Problems

A characteristic of the engineer is his willingness to face the cold truth about the task to which he addresses himself. Engineers have brought to their jobs a more fully developed intellect than any other class of our citizenry. Sloppy, opportunistic thinking is simply inexcusable in the engineering world. I would be the last to suggest that the engineer abandon the precision of his thinking and his honesty in facing facts. I am merely asking that the same

qualities be brought to bear in so far as possible on the more complex situations which have to do with living organisms and our social life. I fear, however, that in our social and economic life the objectives always must come from that mysterious realm which all engineers and scientists should treat with the greatest respect, but with which engineering and scientific methods are totally unable to grapple.

In brief, then, we wish a wider and better controlled use of engineering and science to the end that man may have a much higher percentage of his energy left over to enjoy the things that are nonmaterial and noneconomic; and I would include in this not only music, painting, literature, and sport for sport's sake, but I would include particularly the idle curiosity of the scientist himself. Even the most enthusiastic engineers and scientists should be heartily desirous of bending their talents to serve these higher human ends. If the social will does not recognize these ends, at this particular stage in history, there is grave danger that Spengler may be proved right after all, and a thousand years hence a new civilization will be budding forth after this one has long laid fallow in a relative Middle Ages.

Experiments in Fatal Electric Shock

In the experiments reported here the authors have studied the relations involved in the maximal effect of electric shock, which is death. These experiments were conducted on rats; the relations of duration, current intensity, and frequency were studied. The results afford an explanation of the common observation that death from high voltage usually is cardiac in origin, and from low voltage respiratory in origin.

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RELATIONS between the intensity and duration of electric current eliciting physiological response have been treated extensively in various publications. A critical review of this literature together with a bibliography may be found in *Physiological Reviews*, v. 8, 1928, p. 501–45. La Pique has found that when the current applied is below a certain level of intensity there is no response (i. e., as in the twitch of a muscle to which electrodes are attached) no matter how long the flow is continued. Conversely, a current of high intensity may fail to induce response if applied for a very short time. Experimental determination has shown that the time required for a given current to produce a minimal response, or conversely, the current required to produce this effect in a given time, may be different for different kinds of animals and in fact for different tissues of the same animals; but for any species of animal or any one kind of tissue the relations of time and current intensity vary approximately inversely with each other.

Experiments concerned with the foregoing have dealt with the minimal responses; the magnitudes of the current required to produce these responses are in the order of milliamperes or fractions of milliamperes. On the contrary, in the experiments reported here the authors have studied the relations involved in producing maximal effect which is death. These experiments were conducted with alternating current, and several frequencies were used to determine their comparative effectiveness.

Electric shock may cause the death of animals or man by either cardiac or respiratory failure. The amount of current of definite duration necessary to cause one of these effects in an animal may differ from the amount necessary to produce a similar effect in a human being, but it is reasonable to assume that any information regarding the effect of electric shock in animals will be helpful in the study of these effects on man. The amount of current and the time necessary to produce death by hyperpyrexia (overheating) obviously must be different for small animals than for man because of the difference in the amount of energy necessary to elevate the temperatures of the respective masses. Data presented in this paper were obtained from experiments conducted on rats, to determine the minimum fatal current for durations of $^1/_{10}$ to 30 sec and at frequencies ranging from 25 to 750 cycles per second. The conclusions reached, which of course refer only to the effects of electric shocks on the rats, are briefly as follows:

1. For shocks of equal durations the current required to kill by cardiac or respiratory failure is larger at high frequencies than at low frequencies.

2. For ordinary power frequencies the curve showing the relation between the time and the current required to kill is a composite of 2 intersecting hyperbolas.

3. Explanation of the shape of the curves (Figs. 1 to 3) is to be

Full text of a paper recommended for publication by the A.I.E.E. technical program committee. Manuscript received Sept. 29, 1933; released for publication Jan. 15, 1934. *Not published in pamphlet form.*

found in the variation in susceptibility of different organs to electric shock; in general, shocks fatal in a short time give rise to cardiac failure; those requiring greater duration, to respiratory failure.

4. Currents smaller than those producing fatal cardiac or respiratory effects, if prolonged, may result in death by hyperpyrexia; but within the range of ordinary power frequencies, hyperpyrexia occurs only after cardiac or respiratory failure.

Experimental Procedure

For each experiment the rat first was anaesthetized with ether and then was tied down on a sheet of hard rubber with its legs projecting through holes suitably placed. Spring clips were attached to each leg to prevent withdrawal and to act as contacts. The 2 front legs were attached to 1 lead from the source of power. The 2 rear legs were attached similarly to the other lead. The contacts were wrapped with cotton soaked in a saturated salt solution to reduce the resistance and minimize burning. Shocks were administered only after the effects of the anaesthetic had passed away.

The location of the leads influences the amount of current necessary to cause death, the effects depending on the vital organs situated in the path of the current. Thus when only the front legs (arms) form the 2 contacts, or when the contacts are made on front and rear legs (arm and leg) the fatal current is lower than when the rear legs alone form the contacts. Indeed it is improbable that death can be produced directly from electric shock when the rear legs form the only path of the current, although death may follow from the burns produced. The major resistance in all animals is at the skin surface and may amount to a thousand or more ohms per square centimeter depending upon the moisture of the skin and, in man, also upon the activity of the sweat glands; the resistivity of the moist tissues beneath the skin is low, equaling approximately that of a 1-per cent solution of sodium chloride.

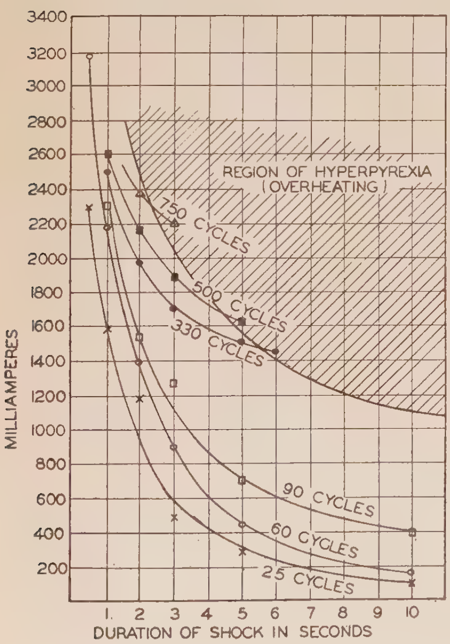


Fig. 1. Minimum currents necessary to cause death from shocks of different durations, for several frequencies

For each time interval studied, and for each frequency, a series of experiments was carried out first to determine approximate values for the fatal amount of current. Shocks with successive increases in voltage were given at intervals of 5 or 10 min until death resulted. In most cases the current and voltage were read from meters properly connected to the circuit leading to the rat. For shocks of short duration it was necessary to determine these quantities by means of an oscillograph. Having limited the field of search by this method, individual rats were exposed to voltages near the fatal value in small steps between successive rats until the minimal fatal current was reached. By repeated experiments for each duration of time and each frequency, the variation of the fatal voltage with duration of the shock could be obtained although at the expense of many rats. A record was kept of the current, voltage, and cause of death for each animal that was killed. If the shock caused the rat's heart to stop beating while its breathing continued for a short period, the cause of death was attributed to cardiac failure. If the shock caused the rat to stop breathing and the heart continued to beat for a short time, the cause of death was recorded as a respiratory failure. Some shocks of long duration caused a pronounced *rigor mortis* which developed even while the current flowed and which was due to overheating. It was found that the fatal voltage for a given time and frequency varied considerably with different rats, but that the current required to cause death was nearly constant. This variation in fatal voltage was due to the differences in the electrical resistances of individual rats. Some variation was found in the time and current required to produce hyperpyrexia. The weight of the animal was of significance in this respect, and to obviate this

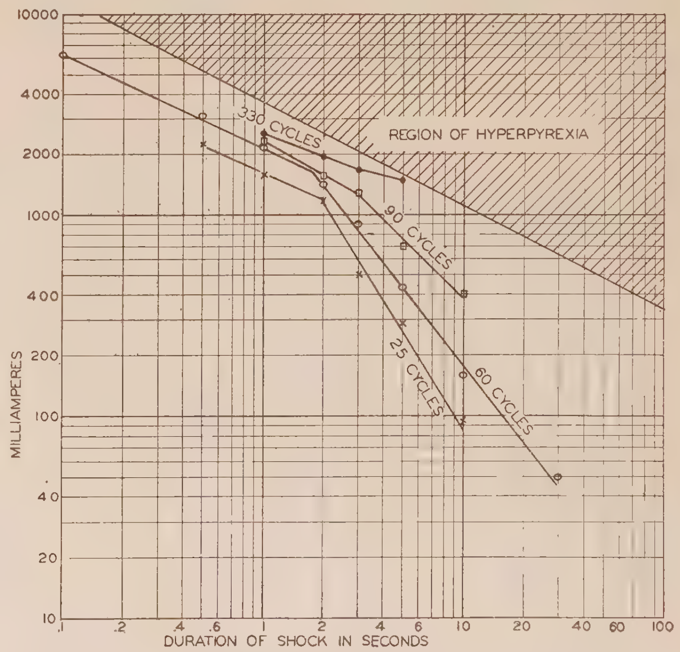


Fig. 2. Minimum currents necessary to cause death from shocks of different durations, for several frequencies (data of Fig. 1 plotted with log scales)

difficulty rats of nearly the same weight were used for all experiments.

The time intervals were controlled by 2 automatic switches. One of these switches was so arranged as to operate synchronously with the voltage supply, closing the circuit when the instantaneous voltage was zero. The second switch, closing at the end of the shock, formed a short circuit around the animal. Oscillograms were taken to check the operation of the switch. The wave form of the current and the time interval of shocks of short duration were determined from the same oscillograms.

Potentials used ranged between 100 and 4,000 volts. The frequencies used in the tests were 25, 60, 90, 330, 500, and 750 cycles per second. Duration of the shocks extended from $^1/_{10}$ to 30 sec. Originally it was intended to employ shorter time intervals, even a single wave; but the amazingly large amount of current necessary to produce death from a shock of less than $^1/_{10}$-sec duration exceeded the capacity

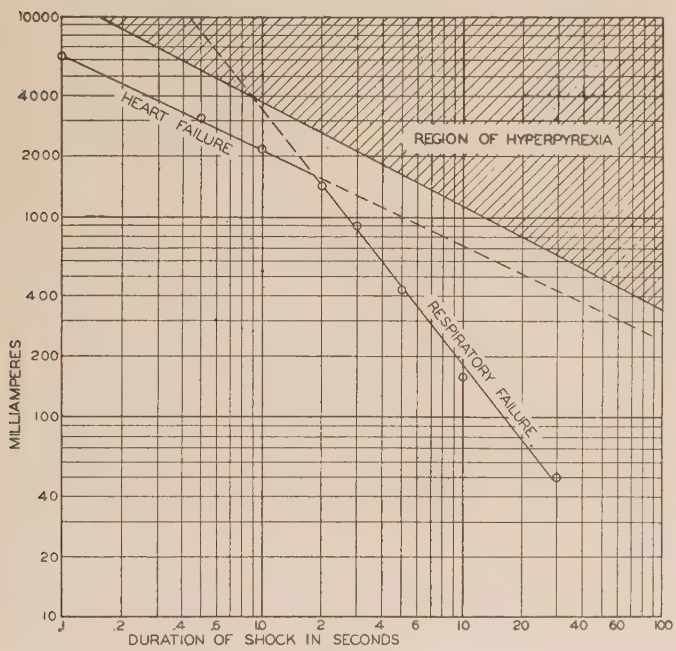


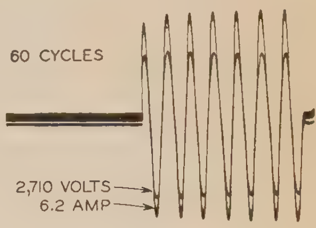
Fig. 3. Minimum currents necessary to cause death from 60-cycle shocks of different durations

of the apparatus used for administering shocks of longer duration. The situation was complicated further by severe burning resulting from the high currents. For the 60-cycle test the current was obtained from a large power supply; for the 25- and 90-cycle tests, from a 15-kva 220-volt alternator; and for those of 330, 500, and 750 cycles, from a 4-kva 220-volt 1000-cycle alternator operating at reduced speed, the desired voltage being obtained by field control on the alternators and by tap changing transformers. In each case the voltage was applied by closing the power circuit on the primary of the transformer and removed by closing a contactor that produced a direct short circuit of the animal before the power circuit was opened. The short circuit prevented any counter or secondary shock that might have been produced during the time of arcking when the main circuit was being opened.

Results

Death from electric shock in a rat is accompanied by a decrease in the electrical resistivity of the animal; a similar effect is not observed during nonlethal shocks. The fall in resistance is of sufficient magnitude, as noted by the sudden increase of current taken

Fig. 4. Oscillographic record of current and voltage during a fatal electric shock



by the animal from the supply, to serve as an indication of the time of death for long shocks. The effect is present also in short shocks as determined from oscillograms; for fatal shocks of $^1/_{10}$-sec duration on 60 cycles the current taken by the rat from a constant potential supply increased approximately 4 per cent. An oscillogram showing the increase in current with time during a fatal shock is shown in Fig. 4.

Results obtained from the final experiments are presented in Fig. 1. Each point shown indicates the magnitude of the minimum sinusoidal alternating current of given frequency necessary to kill an average sized rat from one shock of definite duration indicated by the abscissa.

The curves expressing the relations of time to intensity are influenced by the frequency. Thus for a time interval of 2 sec, 1,000 ma was required to kill when the frequency was 25 cycles; at 60, 90, 330, 500, and 750 cycles the fatal currents for this same time interval were respectively 1,200, 1,300, 1,950, 2,100, and 2,400 ma. The currents required to kill at 750 cycles were so large that hyperpyrexia developed even after shocks of very short duration. Death from cardiac or respiratory failure, which depends upon the maximal response of a vital organ, is affected by the frequency, but death from overheating is not a function of frequency. Hyperpyrexia results when sufficient energy has been supplied to the animal to produce a fatal elevation of body temperature as noted in these experiments by a sensitive thermometer placed in the rectum, and even more clearly indicated by the immediate development of an exaggerated *rigor mortis*. The region of hyperpyrexia is shown by the shaded areas of Figs. 1, 2, and 3. For power frequencies the region of hyperpyrexia is reached only when the duration of the shock exceeds that required to kill by cardiac or respiratory failure.

It may be noted that a few of the points plotted in Fig. 1 do not fall on their respective curves. The experiments showing this divergence were repeated to see if more uniform results could be obtained. These additional tests indicated that the original data were correct. Further analysis of the values given in Fig. 1 is supplied by plotting them with a log scale for both abscissas and ordinates; the re-

sulting curves are shown in Fig. 2. When thus represented the hyperbolic character of the margin of the area of hyperpyrexia is indicated by the resulting straight line bordering the area. The curves for frequencies of 25, 60, and 90 cycles, however, do not appear as straight lines, but show distinct deviation in the region of 2 sec. The curves given in Fig. 1 are therefore the composite of 2 separate intersecting hyperbolas.

An explanation for the double curve, both components of which presumably are hyperbolic if completed, is to be found in a statement made at the beginning of the paper, namely: that the curves showing the relations of the duration of current required to produce the response of different tissues or different organs may not be coincident, but that they are approximately hyperbolic in each case. In the intact animals we are dealing in reality with the response, as death, of the vital organ which is affected by the lowest value of current. Other organs may be able to tolerate a higher value of current before they succumb to the shock, but their activities cease with failure of the organ first affected (death from any occurrence is essentially failure of only one function indispensable to the maintenance of life, rather than to any general disintegration; thus death follows heart failure, although all other organs may be capable of normal operation).

In this series of experiments the rats exposed to shocks of 2 sec or longer, if they escaped hyperpyrexia, almost invariably died of respiratory failure. Those which received shocks of less than 2 sec died of cardiac failure; this fact was emphasized by numerous spontaneous recoveries among rats exposed to presumably fatal currents but of less than 2-sec duration. In a small animal such as the rat, ventricular fibrillation (a common cause of cardiac failure in electric shock) may pass away spontaneously.

The points on the 60-cycle curve shown in Fig. 1 are plotted on log scales in Fig. 3 with the slopes of the 2 component curves extrapolated. It may be seen that for durations of more than 2 sec the curve of cardiac failure falls above that of respiratory failure. Thus when the minimum lethal current is applied, death results from respiratory failure. If, within limits, greater currents are used for the same time duration, cardiac failure may result as well; but since its effects are more rapid than those of respiratory failure, it tends to obscure the effect on the respiratory mechanism.

At time intervals less than 2 sec the conditions are reversed. The curve for respiratory failure falls at a higher current level than that for cardiac failure. Then, in cases of spontaneous recovery from ventricular fibrillation in the rat, currents greater than the minimal fatal amount may cause death by respiratory failure. The complications presented here explain some of the lack of uniformity in the results of experiments to determine the cause of death from electric shock on rats and other animals when precise attention is not given to the minimal fatal currents. The findings of the present tests afford an explanation for the common observation that death from high voltage is usually cardiac in origin, and from low voltage respiratory in origin.

Actions on Electric and Magnetic Units

The following authorized statement of the actions taken at the Paris meeting of the committee on electric and magnetic magnitudes and units of the International Electrotechnical Commission, prepared by Dr. A. E. Kennelly, chairman of the E.M.M.U. committee, is based upon the minutes of the meeting, as circulated among the various I.E.C. national committees. This statement, distributed by the I.E.C. General Secretariat in London, is, however, necessarily subsidiary to the official minutes (I.E.C. document R.M. 105) which should be consulted by those particularly interested.

By
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THE meetings (of section *B* on electric and magnetic magnitudes and units (E.M.M.U.) of advisory committee No. 1 on nomenclature, of the International Electrotechnical Commission, October 5 and 6, 1933) were held at the headquarters of the Société Française des Electriciens, 14 rue de Staël, Paris. The I.E.C. committees of 9 countries (France, Germany, Great Britain, Holland, Italy, Japan, Spain, Sweden, and the United States) were represented by delegates. The national committees of 3 other countries (Norway, Poland, and Roumania) sent in written opinions upon the subjects appearing on the agenda, which had been circulated some months in advance.

There were also in attendance Dr. A. F. Enström, president of the I.E.C., C. le Maistre, general secretary, as well as Prof. H. Abraham, general secretary of the International Union of Pure and Applied Physics, an invitation having been sent to the S.U.N. committee (symbols, units, and nomenclature) of that Union, to attend the meeting.

The minutes of the last preceding E.M.M.U. committee meeting, held in London, September 18, 1931 (I.E.C. document *R.M.* 97), were read and approved.

Name for the Practical Unit of Magnetic Flux

It was unanimously agreed to recommend to the I.E.C. national committees, the name *weber* for the

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practical unit of magnetic flux Φ, which is equal to 10^8 *maxwells* or c.g.s. magnetic units. The name *pramaxwell* had provisionally been adopted at Oslo in 1930 for the same quantity; but objection had arisen in some national committees to the name *pramaxwell* while other national committees were content with it, or at least with the prefix *pra* as a means for effecting a transfer from a c.g.s. unit to a corresponding practical unit. The question rose as to whether, in view of the proposed adoption of the *weber*, the use of the *pramaxwell* and also of the *volt-second* should be discontinued. It was agreed to transmit this question to the national committees; but it was suggested that in order to maintain continuity in I.E.C. decisions, it might be desirable to emphasize the recommendation of the *weber*, but to leave the use of the prefix *pra* open to those who might desire for any reason to continue its use. It was also pointed out that as a matter of historical mischance, the name *weber* had been proposed by various international gatherings, in the past, for various practical magnetic units; so that it was very desirable, now that the *weber* had come before the I.E.C., that its attribution to the practical unit of magnetic flux should be definite and final.

Symbol $\mathfrak{F}$ for Magnetomotive Force (mmf)

It was agreed to recommend to section *C* on letter symbols, of I.E.C. advisory committee No. 1, that the list of electrotechnical symbols adopted at the Berlin meeting of 1913, be modified in such a manner as to make $\mathfrak{F}$ the recognized symbol for magnetomotive force and Φ the recognized symbol for magnetic flux, with no alternatives or symbols of second preference in either of these cases.

Modification of the Definition for Magnetic Flux Density B

At the I.E.C. Oslo meeting of 1930, the definition adopted for magnetic flux density B was:

"The magnetic flux density B is a vector which represents in magnitude and in direction, the state of total polarization due to a magnetic field."

Since this definition involves the attribution of polarization even to a vacuum or free space, it was considered desirable to add the following sentences, for the purpose of clarification:

The value of the flux density at a point may be determined either by the mechanical force exerted on an element of conductor carrying a current and placed at the point; or from a measurement of the electromotive force in an elementary circuit surrounding the point.

These references to the laws of Ampere and Faraday in the definition met with unanimous approval.

Magnitude of the Practical Unit of Magnetomotive Force (mmf)

The question was considered as to whether, in the practical series of magnetic units, the unit of magnetomotive force should be the *ampere-turn* or the ampere-turn/4π (*pragilbert*), the gilbert being equal to the 4πth part of the c.g.s. magnetic unit of current in one turn. The same question had been discussed at the last preceding E.M.M.U. committee meeting of London in 1931; at which meeting, marked differences of opinion had been manifested. Similar divergences of usage appear in modern electrotechnical literature. In view of the differences of opinion over the question, it was unanimously agreed to leave the matter open for further study by the national committees. It is recognized that the question is of considerable importance; because if the *ampere-turn* were definitely adopted as the practical unit of magnetomotive force, the practical series of units would logically become rationalized or at least subrationalized; whereas if the 4πth part of one ampere-turn were adopted as the magnitude of the unit, then non-rationalization of the practical magnetic series would be logically involved. It was pointed out that leaving the question undecided, each and every writer is free to use the practical units either in their rationalized or unrationalized form; but it becomes incumbent on writers to indicate clearly which form they employ.

Name for a Unit of Frequency

It was proposed by the Italian committee that the name *hertz* be given to the unit of frequency—one cycle per second. It was brought to mind that the same proposal had been considered twice before by the I.E.C.; but that the majority in favor of the *hertz* had not been held sufficient to justify its adoption. There is, however, an increasing tendency in several countries, toward the use of the *hertz* as name for the frequency unit; so that it seemed desirable to revive the question at this meeting.

The German delegation supported the Italian proposal, indicating that the *hertz* is used almost universally in German technical literature.

The American and British delegations declared themselves unable to support the proposal; not only because the *hertz* was unused in their countries, but also because the name *hertz* was not self explanatory like the phrase *cycle per second*. Moreover frequency of alternation was not discovered by Dr. Hertz and it seemed inconsistent to their national committees that the honored name of *hertz* should be applied to that physical quantity, in which various branches of science and engineering other than electrotechnics were also interested. Nevertheless, if the *hertz* could be transferred from one cycle per second to one million cycles per second, there seemed to be a possibility of overcoming these objections and of introducing it for applications in the high-frequency range, in place of the phrase *megacycles per second*.

The German delegation indicated that their committee considered it would be impracticable to change the *hertz* to one million cycles per second, in view of established usage, and that various pieces of apparatus were in service marked in *hertz* as one cycle per second. A vote being then taken on recommending the adoption of the *hertz* as the name of the unit of frequency (one cycle per second), and submitting the matter to the approval of the national committees, 7 countries voted in favor (France, Germany, Holland, Italy, Poland, Roumania, and Spain), with 3

opposed (America, Great Britain, and Japan), with 1 country abstaining (Sweden).

Name for the Practical Unit of Conductance

It was proposed by the Italian committee that the name *siemens* should be assigned to the practical unit of conductance. It was pointed out that the German committee had first made the proposition in 1911, and had followed it up on various occasions since that date.

Several delegates pointed out that although the name *mho* had never been internationally adopted for the practical unit of conductance, yet it had come into extensive use in technical literature. Other delegates expressed opposition to the *mho*, as being an unsatisfactory name; while yet other delegates considered that there was no need for a name for the practical unit of conductance. A vote was then taken on the question of whether it was desirable to assign an international name to the practical unit of conductance. Six countries voted affirmatively (France, Germany, Holland, Italy, Poland, and Roumania). Three voted negatively (America, Great Britain, and Sweden). One country abstained (Japan). It was agreed to report the result of this vote to the national committees, without making any recommendation.

Table I—Proposed Modifications

Modifications that might advantageously be introduced into certain classical magnetic formulas employing c.g.s. magnetic units, in view of the international conventions recently recommended by E.M.M.U. committee of the I.E.C. in 1930–31.

In Non-Magnetic Media, i. e., free space, a vacuum, or air assumed to be so nearly equivalent to a vacuum that its correction for magnetization may be ignored:

A. *Magnetomechanical Force f*, between 2 like poles, assumed as free point poles, each of strength m c.g.s. units, separated by a distance of r centimeters, in a nonmagnetic medium of space permeability μ_0, the *numerical* value of which is unity in the classical c.g.s. magnetic system:

Revised Formula — **Classical Formula**

$$f = \frac{m^2}{\mu_0 r^2} \quad \text{instead of} \quad f = \frac{m^2}{r^2} \tag{1}$$

B. *Intensity of Tractive Force f'* or *Tension per Square Centimeter* exerted across an air gap or entrefer, between opposed parallel plane polar surfaces, over which the uniform magnetic flux density is B *gausses:*

$$f' = \frac{B_2}{8\pi\mu_0} \quad \text{instead of} \quad f' = \frac{B^2}{8\pi} \tag{2}$$

C. *Magnetic Volume Energy w* in free space carrying uniform flux density B *gausses* and magnetizing force H *oersteds:*

$$w = \frac{\mu_0 H^2}{8\pi} = \frac{HB}{8\pi} = \frac{B^2}{8\pi\mu_0} \quad \text{instead of} \quad w = \frac{H^2}{8\pi} = \frac{HB}{8\pi} = \frac{B^2}{8\pi} \tag{3}$$

In each of the above cases, the numerical results will be the same with the revised formula as with the classical formula, so long as the classical c.g.s. magnetic system is used. With other systems, however, numerical values for μ_0 differing from unity must be used, except with the Maxwell q.e.s. system (quadrant, eleventh-gram, second). In the m.k.s. system (meter, kilogram, second) unrationalized, $\mu_0 = 10^{-7}$, and rationalized $\mu_0 = 4\pi \times 10^{-7}$. In the c.g.s.s. system (centimeter, gram-seven, second) unrationalized, $\mu_0 = 10^{-9}$, and rationalized $\mu_0 = 4\pi \times 10^{-9}$. It seems, therefore, desirable to retain the symbol μ_0 in every instance as generic.

In Magnetic Media:

D. *Formula for Uniform Magnetization:*

$$B = \mu H = \mu_0 H + 4\pi \mathscr{I} \quad \text{instead of} \quad B = H + 4\pi \mathscr{I} \tag{4}$$

where $\mathscr{I}$ is the uniform intensity of magnetization of the material.

If $\mathscr{I} = 0$, $B = \mu_0 H$ instead of $B = H$ (4a)

E. *Absolute Permeability of the Material* μ (Dividing Eq 4 by H):

$$\mu = \mu_0 + 4\pi \frac{\mathscr{I}}{H} = \mu_s + 4\pi\kappa \quad \text{instead of} \quad \mu = 1 + 4\pi\kappa \tag{5}$$

F. *Magnetic Susceptibility of the Material* κ (From Eq 5):

$$\kappa = \frac{\mu - \mu_0}{4\pi} \quad \text{instead of} \quad \kappa = \frac{\mu - 1}{4\pi} \tag{6}$$

Desirability of Introducing the Symbol μ_0 Into Various Working Formulas

In view of the I.E.C. convention adopted at Oslo in 1930; namely that space permeability μ_0 is not a mere numeric, but has physical dimensions, it was unanimously agreed that in the list of working formulas appearing in Table I, it is desirable to insert the symbol μ_0 for space permeability, even when, as in the c.g.s. magnetic system, the numerical value of μ_0 is taken as unity.

Several delegates favored the recommendation to section *C*, that the symbols for absolute permeability should be changed from μ_0 to some other letter, for the reason that it was desirable to have a different symbol for absolute permeability (including permeability of a vacuum), from that for relative permeability, which is universally admitted to be a mere numeric. On putting this proposal to a vote, it was found that 7 countries favored making no change, while 2 favored a change, with 2 countries abstaining. Consequently, it was agreed to keep μ for absolute permeability, and μ/μ_0 for relative permeability, with μ_0 for the absolute permeability of vacuum or free space, as at present.

Use of the Gauss and of the Oersted

The following propositions were presented for consideration by President Janet of advisory committee No. 1, with the object of seeking an agreement with physicists:

1. In order to respect the decisions of the International Electrical Congress of 1900, and also to recognize the general usage of physicists, the *gauss* should continue to be available as the unit of magnetic field.

2. Having given that in the classical electromagnetic system, magnetic field and magnetic induction are quantities of the same dimensions, and also that both among physicists and among electrotechnicians, the usage has extended of giving the name *gauss* to the unit of induction, the use of the name *gauss* for the unit of induction is definitely authorized.

3. Electrotechnicians having found it useful and convenient, for

practical purposes, to give different names, even in the c.g.s. magnetic system to the units of magnetizing field and of induction, the name *oersted* is authorized for the name of the unit of magnetizing field.

It was recognized that the adoption of these proposals would mean annulling the Oslo conventions of 1930, and all of the international agreement concerning magnetic unitology that has been attained since that date.

Several delegates expressed the opinion that the Oslo decisions on this question should be upheld, as otherwise, if H and B were accepted as identical physical quantities, it would be illogical to assign different names to their units, and the confusion which existed prior to the Oslo convention would only be increased. While it was regrettable that no solution could be found that would satisfy all parties, yet various physicists who had been accustomed to express H in *gauss* had already adopted the *oersted* or the *gilbert per centimeter* for H and there were indications that this tendency was increasing. Moreover, much misunderstanding accompanied the use of the magnetic term field (*champ*). This term in its general sense, was susceptible of meaning either field of magnetizing force H or field of induction B. On the continent of Europe, it was generally taken as H, but in the English-speaking countries it was generally understood as B. It was therefore important to avoid using the general term *magnetic field* without specification.

Professor Janet having stated that he was personally in favor of the Oslo conventions, it was finally unanimously agreed that in view of the importance of maintaining the Oslo conventions, no action should be taken on the 3 proposals, concerning the *gauss* and *oersted*.

Inductively Reactive Power in Triangular Vector Power Diagrams

The proposition to adopt a standard method of interpreting unspecified right-angled triangle power diagrams had been considered at the E.M.M.U. committee meeting of London, but had been laid on the table until further proposals were offered by the American committee. These having been submitted, the following resolution was unanimously agreed to:

The committee recommends that in vector power diagrams, inductively reactive power should be indicated as $-j$ *vars* plotted vertically downward, and condensively reactive power as $+j$ *vars* plotted vertically upward, it being understood that generated active power (watts) is indicated by a horizontal line drawn to the right.

This recommendation was directed to be sent to the national committees.

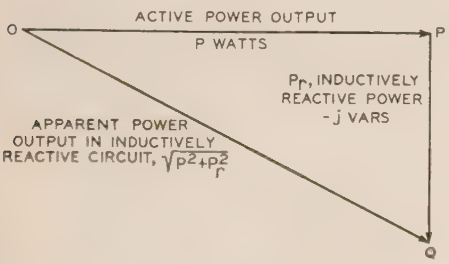

Fig. 1. Interpretation of unspecified power diagrams

Name for the Associated Practical Unit of Resistance for 1,000 Ohms

The proposition of the British committee to adopt the name *kilohm* as an abbreviation for the term *kiloohm*, representing 1,000 ohms, was unanimously approved.

Extension of the Existing Practical Units Into a Complete Practical Absolute System

Attention was called to the resolution adopted at the Chicago meeting (June 24, 1933) of the American section of the International Union of Pure and Applied Physics:

The existing series of practical electrical units (*ohm, volt, ampere, coulomb, farad, henry, joule,* and *watt*) may advantageously be extended into a complete absolute practical system, either through the medium of the meter-kilogram-second (m.k.s.) or through the centimeter-gram-seven (10 Tonnes) and second (c.g.s.s.). Of these, the m.k.s. system is preferred for consideration.

The m.k.s. system here referred to is the system advocated by Prof. G. Giorgi since 1901.

Prof. Giorgi, who was present, gave by invitation a short explanation of the m.k.s. system and answered various questions asked by delegates. He also accepted an invitation to send to the Central Office in London a memorandum summarizing the general principles of the m.k.s. system, and of its applications to electrotechnics, for distribution to the various national committees.

Mr. Brylinski, the president of the French committee, made a short exposition of the comparative merits of the c.g.s.s. and m.k.s. systems, pointing out the superiority of the m.k.s.

Prof. Abraham drew attention to the fact that although the m.k.s. system is independent of the c.g.s. system, yet they are definitely connected, and the fundamental units of the m.k.s. system, in regard to length and mass, are identical with those whose standards are maintained by the International Bureau of Weights and Measures at Sèvres, namely, the *meter* and the *kilogram*. He advocated the importance of keeping the unit of resistance in the m.k.s. system (the *ohm*) at the definite value of 10^9 c.g.s. absolute units of resistance.

The following resolution was then unanimously adopted:

Section B of advisory committee No. 1 on nomenclature, having heard with interest Mr. Giorgi's communication on the m.k.s. system, and supporting the resolution adopted by the American section of the International Physical Union at Chicago, in June 1933, decides to invite the national committees to express their views on the extension of the existing series of practical units used in electrotechnics into a complete coherent system having for its fundamental units of length, mass, and time, the meter, kilogram and second, and as fourth unit, either that of resistance defined as 10^9 c.g.s. magnetic units, of the corresponding value of the magnetic permeability of free space.

It may be observed that while the general introduction of the m.k.s. system would in no way affect the operation of the classical c.g.s. system of Maxwell in the general field of physical science, it would enable electrotechnicians to carry on their work independently through their own absolute system in which their practical units were constituent elements.

Steam Ejector System For Car Conditioning

Steam ejector refrigeration for railroad passenger car air conditioning has been proved to be practicable. Equipment of this type which has been developed and thoroughly tested is described in this article.

By
C. M. ASHLEY

Carrier Engineering Corp., Newark, N. J.

AIR CONDITIONING, that new art whereby comfortable conditions in stores, offices, and theatres are maintained during the summer as well as in winter, has definitely entered the field of the railroads. During 1930 to 1932 an increasing number of semiexperimental installations of air conditioning equipment were made on passenger cars. These brought forth an unmistakable public response to the controlled temperature and humidity, good ventilation, and freedom from dust and noise thus made possible. Not only was it shown that more people used air conditioned trains than had used the unconditioned ones, but that there was a net increase in the number of people using rail transportation. With the imminent prospect of equipping thousands of cars, a number of equipment manufacturers, as well as the railroads themselves, began to take stock of the peculiar problems inherent in railroad air conditioning, many of which had been ignored in the earlier designs. These problems are:

First, and most serious of these problems, is that of motive force to drive the equipment. It has been found that the temperature in a car may rise as rapidly as $^2/_3$ deg per minute when the air conditioning apparatus is stopped. This quickly creates an intolerable condition. To assure continuous cooling, the motive force must be available continuously and regardless of train speed.

Second, and a natural outgrowth of the first, is that the demands upon the existing power sources, steam and locomotive power, must be moderate both from a standpoint of economy and in order to prevent an unfortunate reaction on the train performance.

Third, new hazards must be avoided. It was early recognized that no system using such common but noxious refrigerants as ammonia or sulphur dioxide would be tolerable, nor would a gasoline engine drive be acceptable.

Fourth, the new air conditioning system must be on a car-unit basis. This demand results from the operation of cars, both Pullman and railroad owned, on more than one line and together with various other types of cars. Where trains do operate as a unit they may some day use a centrally located refrigeration system for the whole train.

Fifth, the system must be reliable in its operation. It should likewise be accessible for repair as well as for routine servicing. The railroads find equipment requiring extensive maintenance is expensive regardless of first cost.

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Besides these major considerations there are a number of others which will be apparent, such as a reasonable first cost, adaptability to available space, light weight, flexibility as to altitude, climate, etc.

Two Types of Installations

During the summer of 1933, several types and a number of makes of air conditioning equipment were tried out by different roads, some of the roads going so far as to try out several types while others equipped whole trains with air conditioning. Of these equipments the air conditioning apparatus as distinguished from the refrigeration apparatus, is identical in principle for all. Air from the car, and from outdoors, is mixed and drawn over coils chilled by some refrigeration process. The air passes through a fan and is then discharged either directly or through ducts into the upper part of the car. In passing over the coils, not only is the air cooled but moisture is condensed out as well. The windows are kept closed at all times, thus excluding dirt and noise, while ventilation and usually cleaning of the outside air is accomplished by the air conditioning unit. Those systems which did not draw in some outside air were not successful and have since been replaced.

The approach to the problem of providing refrigeration for chilling the coils for cooling the air has been along diverse paths. In general, we may group these into 3 types. First, there is refrigeration using ice as a cooling means. A variety of systems of this type, designed largely by the railroads themselves, have in common a bin and tank into which ice is loaded at the beginning of the run and possibly during the run if it is long. Cooled water passes from a pump through the cooling coils of the air conditioner. It is then sprayed over the ice, chilled, and returned to the pump.

The low first cost and simplicity of this equipment would have precluded all others had it not been for the operating expense, and, even more, the trouble of maintenance. As it is, this type of system has a useful but limited field.

The second line of attack was through the applica-

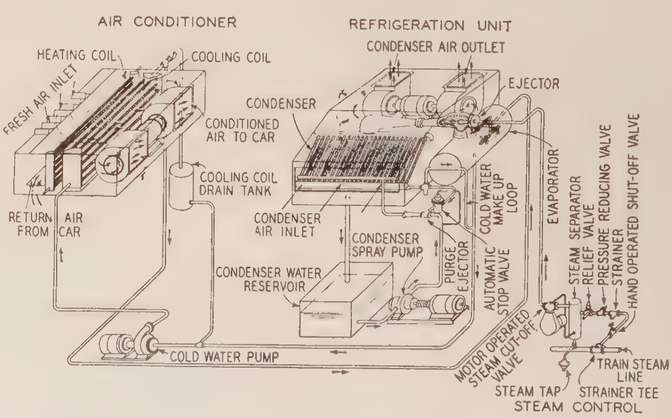


Fig. 1. Diagram of the steam ejector car conditioning system

tion of mechanical refrigeration. In the various systems of this type the power and drive problems received various treatments. Representative of the more workable solutions is the use of a belt or gear driven axle generator, a storage battery, a motor driven reciprocating compressor with a forced air-cooled finned coil type of condenser. The refrigerant used is freon, relatively harmless when compared with ammonia or sulphur dioxide. The cooling of the air is by the direct evaporation of the refrigerant in the coil located in the air stream. Such a system designed to produce 6 tons of refrigeration, requires 11 kw for its full operation with moderately high outdoor temperatures. A storage battery to supply the air conditioning system and lights for 6 hr without recharging must have 2,000-amp-hr capacity. The generator should be of 20-kw capacity in order to meet a wide variety of road conditions. The designer of such a system must solve the problem of transmitting as much power as this at relatively low train speeds; the refrigeration compressor must require negligible mechanical maintenance even when working under the heavy load imposed by extremely hot weather, and the refrigeration system must be and must remain tight.

Steam Ejector Refrigeration

Mindful of these problems, one company offered a third solution for the refrigeration: the steam ejector refrigeration machine. This is one of nature's modern paradoxes, cooling by the direct application of steam.

Cold water, circulating through the cooling coil of the air conditioning unit (Fig. 1) receives heat from the air, flows thence to a chamber or evaporator into which it is sprayed. This evaporator is maintained at a vacuum so high that it permits the boiling of the water, cold as it is, 40 deg to 50 deg F. The evaporation of a portion of this water cools the rest which is then recirculated by a pump to cool the air further.

The steam ejector maintains the vacuum which permits this evaporation. To do this, steam from the train steam line is admitted through a nozzle to the end of the venturi shaped tube forming the ejector. In expanding from its fixed positive pressure to the high vacuum, it attains an enormous velocity, which permits it to entrain vapor from the evaporator. This vapor enters the ejector near the nozzle. It is first accelerated and mixed with the high velocity steam, then due to the shape of the venturi the mixture is compressed, changing its velocity energy to pressure. The compressed mixture is delivered to a special type of air condenser in which it is condensed. It is apparent that the function of the ejector is like that of the mechanical compressor, to draw refrigerant from the evaporator and compress it so that it can be condensed by giving up heat to the outside air.

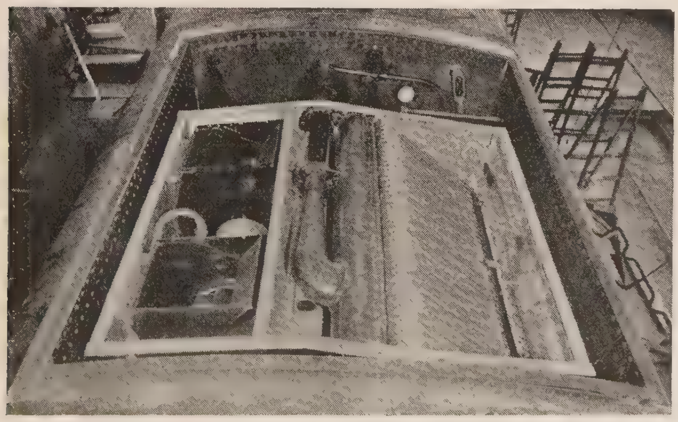


Fig. 2. Refrigeration unit of the steam ejector type, containing evaporator, ejector, condenser, fans, and purge system, located in the upper deck of the car

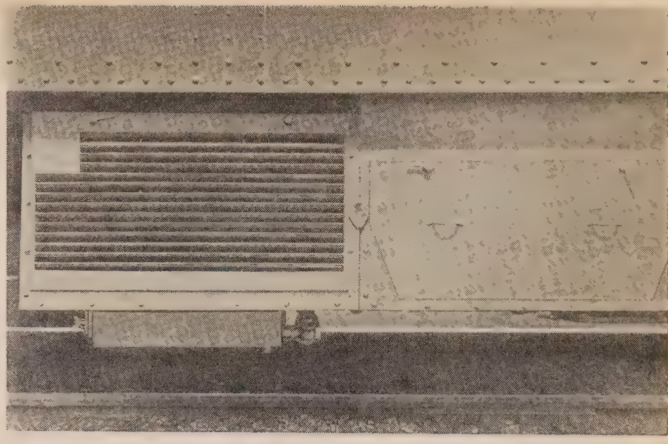


Fig. 3. Alternative location of the refrigeration unit under the car

A part of the condensate thus formed is automatically returned to the evaporator to make up for the evaporation which has occurred. The rest, together with any air leakage into the system, flows into a water jet ejector which discharges to atmosphere at low pressure through spray nozzles.

The nozzles are so arranged that the spray wets the outside of the finned surface condenser while at the same time, air from outside the car is forced over it by means of a fan. The resultant evaporation cools the condenser surface and condenses vapor within the condenser. The air which passes over the condenser is discharged upward and the unevaporated water flows to a reservoir from which it is repumped as needed.

As can be seen, the system consists of a number of more or less closed circuits: the cold water circuit, the refrigeration circuit, the air-condensate removal circuit, and the condenser heat removal circuit. These are so interrelated that it is necessary only to supply steam for compression, a small amount of water for condensation and power for air and water circulation, to obtain refrigeration.

Electrical Equipment

The fact that the motive force for the refrigeration compressor is steam, does not exclude electrical equipment from the steam ejector system. It rather reduces the electrical problems to those which have already been successfully solved. Four small motors

are required to operate fans and pumps, which are of the centrifugal type; one fan is required to circulate the air in the car, another to circulate outside air over the condenser; one pump is required to circulate cold water through the air conditioning unit while another provides water for the purge and condenser of the refrigeration machine. The total power of these 4 is 2.25 kw under normal voltage (32 volts). To supply a continuous source of power for the air conditioning system regardless of train speed, a 5-kw axle driven generator together with a 1,000-amp-hr storage battery is more than ample, the battery being able to serve the other electrical demands of the car as well. This equipment is of a size already accepted for lighting service and involves no new design problems. The motors are started by across the line type starting switches. The operation of the cooling system is controlled through relays by a car temperature switch, a steam pressure switch, and a vacuum switch of conventional design. These operate the motor switches and an electrical valve on the steam line. By means of these switches the system is not only operated automatically but started automatically as well. In the winter time, the air conditioning unit introduces warmed air into the car controlled in the same manner as is the present car heating system, through a system of electrical thermostats and valves.

Besides the electrical control elements the steam pressure to the ejector is controlled and the quality is maintained close to saturation.

Arrangement of Refrigerating Equipment

For convenience of handling and installation, the refrigeration equipment has been grouped into several units. Largest of these is the refrigeration unit which contains the evaporator, ejector, condenser, fans, and purge system. Originally the car had this unit located in the upper deck (Fig. 2). However, to make installation easier on existing cars, an alternative location under the car is now employed (Fig. 3). The 2 pumps are mounted separately under the car or inside. The steam control equipment is grouped in an enclosure under the car and the condenser make-up tank is located adjacent to the condenser pump under the car. All of these elements have great flexibility as to their relative locations. The air conditioning unit (Fig. 4) has been located, like the refrigeration unit, in the upper deck of the car and is arranged to draw outside air through filters in both sides of the deck. This unit is now available in an alternate location (Fig. 5) as a vertical unit within the car.

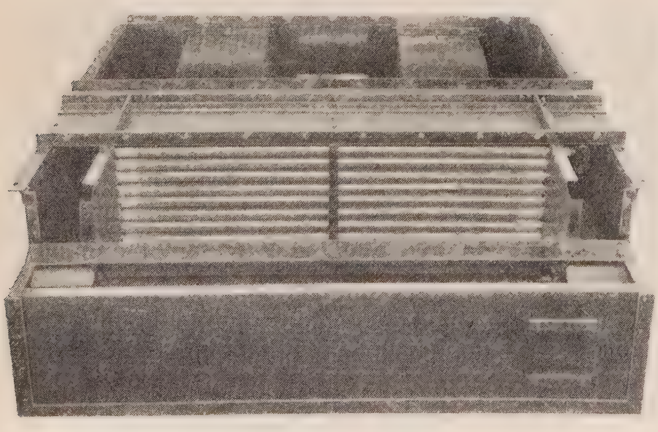


Fig. 4. Rear top view of the air conditioning unit for location in the upper deck. The cover is removed, showing the cold water circulating coils and fan housings

Fig. 5. Air conditioning unit arranged for vertical mounting inside the car

Comparison of Characteristics

Steam ejector refrigeration has some interesting differences in characteristics from other types of refrigeration. These are illustrated in Figs. 6 and 7. In Fig. 6 is shown how the temperature of the condenser affects the performance of the steam ejector refrigeration, and for purposes of comparison, the effect on a mechanical refrigeration system. The part of each curve which would be used in practice under usual summer weather conditions is shown in solid lines and the projection to higher temperatures in dotted lines. It is apparent that within the limits of normal operation the condenser temperature has no effect whatever on the capacity of the steam ejector system.

In Fig. 7 is shown the variation of refrigeration capacity with cold water temperature. It is apparent when comparing the steam ejector performance with that for a mechanical compressor that the variation in capacity is much more rapid in the former. As the result of this characteristic, the steam ejector machine is less affected than is the mechanical

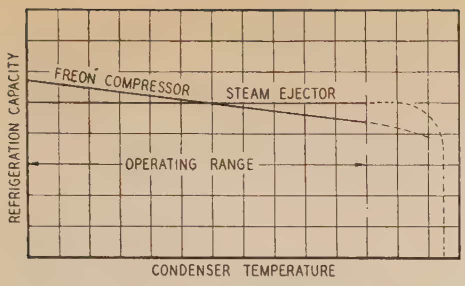
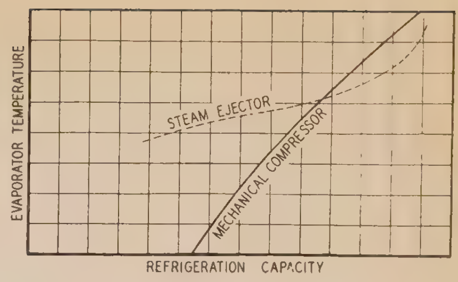


Fig. 6. Effect of the temperature of the condenser on refrigeration capacity for 2 types of refrigeration

Fig. 7. Variation of refrigeration capacity with cold water temperature for 2 types of refrigeration



refrigeration machine by changes in load and is better able to carry an overload.

Refinements in Condenser Design

The main elements of the steam ejector system were well proved in other fields or uses. The steam ejector itself has a history of 30 years or more as a refrigeration compressor but has only recently gained favor due to its special adaptability to air conditioning refrigeration. However, there were some very interesting problems to be solved in the development of this system. Perhaps the most important of these was that of the condenser design. The finned evaporative type air condenser is in principle old but by taking advantage of new highly effective forms of surface and by the use of forced circulation, the space occupied and the power required for condensation of the steam has been greatly reduced over conventional types of equipment. An essential part of the design is the use of an all closed system in which a vacuum is maintained continuously in distinction to earlier types using a jet condenser and a spray air conditioner. By the use of a closed system, it is possible to start refrigeration almost instantly after a short shutdown instead of having to wait until the purge equipment has been able to draw the required vacuum. It is also possible to reduce the size of the purge, as the entrained air which is brought into an open system must no longer be removed. The smaller purge system makes possible another combination of function by the use of a water ejector which acts as both purge and condensate pump and which makes use of the same stream of water with which the condenser surface is flooded. Another elimination of equipment is accomplished in the evaporator feed which returns water from the condenser to the evaporator by balancing the pressure difference with a gravity head, removing the necessity of a valve to control the feed.

Problem of Air Leakage Overcome

One of the bugaboos often raised against vacuum refrigeration is that of air leakage into the system. A very common assumption is that a vacuum refrigeration system must be tighter than one operating under a pressure. This is not so. A leak which would permit the full continuous operation of the steam ejector system would cause a mechanical refrigeration system to begin to lose in refrigeration capacity in 15 hr and be inoperative in 27 hr, due to loss of refrigerant charge. Moreover, such a leak would cost in refrigerant at the rate of $16 per day. Obviously, such a situation would be intolerable for the mechanical system while not materially affecting the steam ejector system. This leakage rate, corresponding to the air removal capacity of the purge of the steam ejector system, is many times the acceptable test leakage. The excess purge capacity is provided to permit the system to be put into operation quickly in the event the vacuum should be lost completely and also to provide against contingencies which may be encountered in railroad service.

The steam ejector system is designed and constructed with great care to obtain tightness. One of the most common sources of leakage is a stuffing box. There is, however, but one stuffing box in the vacuum system and this is continuously liquid sealed. The joints in piping and apparatus are in large measure either fused or gasketed. The automatic valves which connect the steam supply and purge discharge to the vacuum are closed at all times that the system is not in operation and in addition they are liquid sealed. While tightness of these valves is desirable it is in no way essential to the successful operation of the system.

Freezing Guarded Against

Freezing is avoided either by draining the system or where winter cooling does not allow this, the same precautions are taken which prevent freezing of existing water storage tanks on cars. A steam line, turned on seasonally or thermostatically, parallels the heat insulated, water containing equipment, thus maintaining it above freezing. To provide against the possibility of freezing those parts which are exposed to the outside air, an internal drainage system is provided which insures their freedom from water at all times when the system is not in operation.

Steam Requirements

No matter how effective a system may be for cooling one car of a train, its ultimate value depends upon its usability for an entire train. The mechanical system is faced with a large power demand; the steam ejector system must keep its steam requirements within the capacity of existing lines if success is to be attained. At the start of the development the criterion was set up that it should be possible to cool as many cars as can be heated with the steam lines. This criterion has been fulfilled in the existing equipment providing 6 tons of refrigeration per car. Early in the development an actual train was tested. Using the 2-in. metallic couplers now becoming standard equipment, it was possible to supply steam

for 15 cars at one time with this equipment.

A problem akin to that of getting steam to the end of a long train is that of getting steam at all on electrified lines. Steam must be available for heating, however, even on electrified lines, because of the cars which come from other lines and are unequipped to be heated by electricity. This same steam generating equipment, usually an oil boiler located in the locomotive, may be used for supplying steam to steam ejector refrigeration machines in the summer. Furthermore, if electricity is to be used directly for heating or for operation of refrigeration machines, additional equipment must be provided over and above that which supplies steam or power on unelectrified lines. Thus, the presence of a direct source of electricity is not as helpful as might seem to be the case at first thought.

Effect on Train Operation

The question of the effect of the refrigeration systems upon the train operation and cost is one of paramount concern, both with mechanical and steam ejector refrigeration. Considering first the question of operation some figures may be of interest.

Train lighting systems are commonly designed with a generator capacity nearly twice the expected load, to provide additional current to charge a storage battery for use during slow speed operation and during stops when the generator is not delivering current. There seems to be good reason to maintain the proportion for the cooling load. Even where charging and operation in terminals are from an outside power source, it is still necessary to provide sufficient generator and battery capacity to balance the load in order to assure continuous operation under adverse conditions.

On this basis, the generator capacity required for refrigeration, for battery charging, and for one kilowatt of continuous lighting load will be 20.5 kw for a 6-ton mechanical system and 5.9-kw for the 6-ton steam ejector system. The load imposed upon the power supply by the mechanical refrigeration system varies with the outside air temperature; that imposed by the steam ejector system remains constant. In picking the load of the mechanical system, moderately warm weather, not the extreme of summer heat, has been used. After taking into account the efficiencies of drives and generators, the figures of capacity given above become 43 indicated horsepower at the locomotive for the mechanical system and 13 indicated horsepower for the steam ejector system. Battery capacity to operate the air conditioning system and lights for 6 hr without recharging would have to be 2,070 and 610 amp-hr, respectively. The car which has no refrigeration but has some disc fans for air circulation in the car would have a generator capacity of 2.3 kw equivalent to 5 indicated horsepower at the locomotive.

Now, let us assume that a train consisting of one locomotive and 12 passenger cars is moving at 30 miles per hour up a grade such that the locomotive is just able to maintain the speed. Let us assume that the train is equipped with axle generator train lighting equipment which is fully on the line at 30 miles per hour. If, then, steam ejector refrigeration is added with its drag on the locomotive, the locomotive can pull only 11.5 cars, or half a car less than with the lighting generator only. If, on the other hand, the train is equipped with mechanical refrigeration, then the locomotive can pull only 10 cars or 2 cars less than with the lighting generator.

The effect of the refrigeration power demand is either to decrease the train speed or require the use of a second locomotive in such cases as given above. At lower and at higher speeds and on level tracks where the train has ample power, the effect of the refrigeration is not so marked although it must be recognized as a factor in slowing down acceleration. Obviously, all of these effects are greater in magnitude for the systems having the greater power demand on the locomotive.

Fuel Cost

One of the most important elements of the operating cost is the cost of fuel and of the services which go into the generating of steam. For a 6-ton refrigerating and air conditioning system of the steam ejector type, the steam required to drive the generator is 223 lb per hour per car, the steam for the ejector is 200 lb, and the line loss about 35 lb, making a total of 458 lb per hour. With steam costing 25 cents per 1,000 lb this makes an hourly cost with the refrigeration in operation of 11.4 cents. Of this, however, 2 cents would have been spent to pull the lighting generator without refrigeration, making a net addition due to refrigeration of 9.3 cents per hour. In the case of the mechanical refrigeration the amount of steam required to drive the generator would be 725 lb per hour on a similar basis and the gross cost would be 18.1 cents per hour. The net cost of steam for refrigeration after deducting the cost of steam for driving the lighting generator would be 16 cents per hour.

Conclusions

It is apparent that the steam ejector refrigeration system conforms to every criterion laid down at the beginning of this article. The principal motive force is the readily available steam of the train line, the electrical power requirements being moderate. The steam ejector system is not excessive in its demand for either steam or locomotive power. The use of water as a refrigerant presents a hazard about as nearly zero as it is possible to attain. The system is on a car unit basis independent of other train equipment and requiring but the normal supply of steam and the occasional motion of the train to maintain refrigeration. The steam ejector principle is by nature reliable for refrigeration, and the operating records of a season attest to the low maintenance costs of the system in practice. Considerations of first cost, suitability to available spaces, weight, flexibility, and a number of other practical factors are satisfactory with the use of the steam ejector refrigeration for railroad passenger cars. It is thus apparent that this system is a contender of promise for the railroad air conditioning business.

Shunt Resistors for Reactors—II

Shunt resistors applied to current limiting reactors used on large electric power systems function to reduce voltages caused by reflections and oscillations, to provide an avenue of escape for bus disturbances, and to reduce the voltages across the reactors. To be suitable for this purpose, a resistor must have an inverse characteristic such that its resistance during short circuits is many times that during transient conditions. The material known to the trade as "thyrite" fulfills these requirements admirably. A method of calculating the effects of such a resistor, with results given in convenient curve form, is presented in this paper.

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CURRENT LIMITING reactors are used universally on large metropolitan systems to limit the short-circuit currents caused by faults. Usual practice is to place a current limiting reactor in series with each feeder or tie, as well as in the generator leads and for bus sectionalizing purposes, as indicated in Fig. 1. Unfortunately, however, as has long been recognized, a reactance in series with a line or cable acts as a reflection point to traveling waves such as are initiated by lightning, arcing grounds, or switching surges; and furthermore it enters into oscillation with the capacitance of the bus and connected apparatus, thereby causing dangerous transient voltages to appear on the bus. Moreover, transient disturbances originating on the bus are trapped there temporarily, and are unable to find immediate relief by dissipation in the outgoing feeders. These difficulties, inherent in the simple reactor may be circumvented by equipping each reactor with a simple shunt resistor of proper characteristics. Such a resistor functions to reduce substantially the voltages caused by reflection and oscillations, to provide an avenue of escape for bus disturbances, and to reduce the voltage across the reactor as well as its internal transient.

Full text of a paper recommended for publication by the A.I.E.E. committee on protective devices. Manuscript submitted Oct. 26, 1933; released for publication Jan. 1, 1934. *Not published in pamphlet form.*

In a previous paper these advantages were pointed out and illustrated by calculations and tests (see "Shunt Resistors for Reactors" by F. H. Kierstead, H. L. Rorden, and L. V. Bewley, A.I.E.E. Trans., v. 49, 1930, p. 1161–77). It is the object of the present paper to extend both the calculations and tests, and to show how the effects of a thyrite shunt resistor may be calculated with precision. The method is based upon rigid mathematical solutions given in the Appendix. By fortunate circumstances, however, the relative values of the circuit constants are such that a complicated circuit can be solved very simply numerically and the calculation reduced to a set of curves (see Fig. 6). From these curves it is possible either to determine the thyrite constant necessary to limit the voltage at the reflection point to a given value, or conversely to determine what the voltage would be for a given thyrite resistor. The curves consider only the reduction of reflections, for the reason that a thyrite resistor capable of reducing reflections also will reduce the amplitude of oscillations to negligible values, and provide an immediate avenue of escape into the outgoing feeders for any transient disturbance originating on the bus.

From the curves given in this paper it is clearly evident as to what extent a thyrite shunt resistor is beneficial. Although the virtues of a suitable shunt resistor long have been recognized by those familiar with the problem, this is believed to be the first occasion where specific cases can be demonstrated quickly by inspection of a set of curves. In brief, the thyrite shunt resistor is a simple, inexpensive and reliable device for reducing in the order of 20 to 40 per cent transient voltages that can appear at reactors in service.

Circuit Constants

A typical system, such as indicated in Fig. 1 reacts to an incoming traveling wave like the simplified circuit of Fig. 2A in which are $(N+1)$ feeders of surge impedance Z, each with a series reactor L and shunt resistor R. The bus itself has a capacitance C; if transformers or other apparatus are connected thereto, they contribute a certain amount of capacitance, representative values of which are given in the following table:

Apparatus	Capacitance in μf Max.	Min.	Avg.
Generators (salient poles)	0.001	0.0002	0.0006
Generators (turbine)	0.001	0.0001	0.0005
Transformers (distribution)	0.002	0.0004	0.0010
Transformers (power)	0.001	0.0002	0.0005
Transformers (nonresonating)	0.003	0.0010	0.0020
Bus systems	0.015	0.0020	0.0050

For traveling wave calculations this capacitance may be regarded as lumped.

The surge impedance of cables varies from 30 to 100 ohms, depending upon the construction of the cable, but an average value of 50 ohms will fit most cases. If the cable sheath is not well grounded, the

effective surge impedance will be higher; in fact, a cable with insulated sheath has a surge impedance of several hundred ohms. In this paper the cable sheaths are assumed to be thoroughly grounded, and numerical calculations are based on a cable surge impedance, Z, of 50 ohms. The surge impedance of overhead lines is approximately 500 ohms.

The inductance of current limiting reactors is given by

$$L = \frac{1.59\ (\%\ \mathrm{IX})\ (\mathrm{kv})^2}{f\ (\mathrm{kva})} \qquad (1)$$

Thus on a 13.8-kv 7,150-kva circuit with 3 per cent reactance, the inductance is 0.0021h. For traveling wave calculations this inductance may be regarded as lumped. A reactor also possesses distributed capacitances to ground and between turns; but while

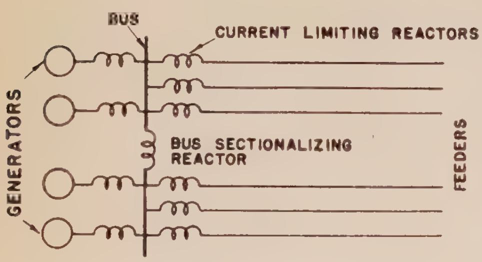


Fig. 1. Typical system layout employing current limiting reactors

these capacitances are vitally important as far as internal oscillations in the windings of the reactor are concerned (see previous paper) they exercise no particular influence on the reflected and transmitted waves, and therefore may be ignored for purposes of the present paper. The normal series resistance of a

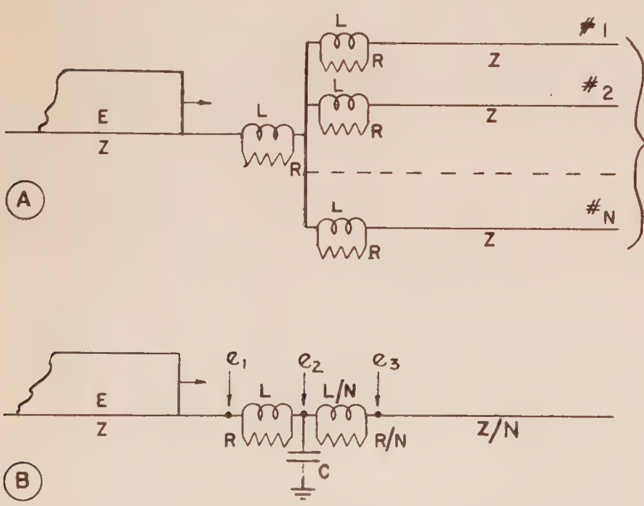


Fig. 2. Equivalent circuits to traveling waves

A. Actual bus and feeders B. Equivalent circuit

reactor is quite small, but the transient skin effect (see previous paper) becomes of some importance in determining the rate of decay of the transient oscillations across the reactor. However, the decrement due to this cause does not change materially the crest voltages obtained. For this reason the reactor will be considered free of losses in this discussion.

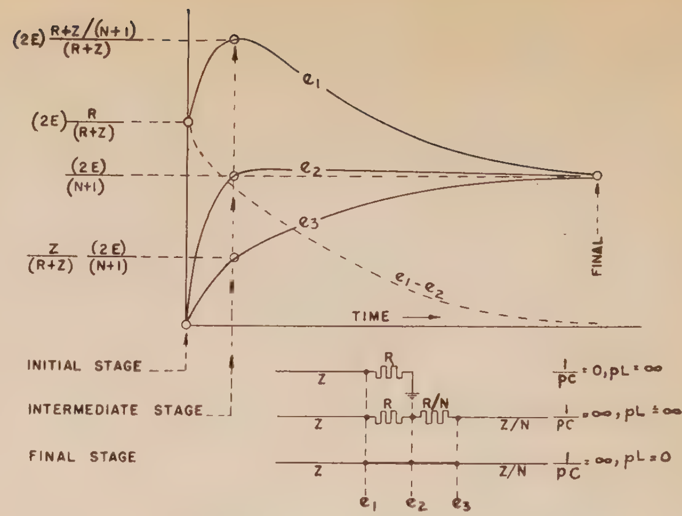


Fig. 3. Calculation of the limiting points of the transient

A *constant* shunt resistor is of little use, since its resistance must be so high, in order to stand short circuit conditions, that it will not pass enough current upon the impact of a traveling wave to provide any relief to the system. Thus, as has been pointed out before (see previous paper) a constant shunt resistor capable of substantially reducing transient voltages would have to absorb energy on a 13.8-kv circuit, under short-circuit conditions, at the rate of 1,274 kw. A resistor capable of absorbing so much energy without overheating would be prohibitive in size and cost. For this reason a suitable shunt resistor must have an inverse characteristic such that its resistance is of the order of 10 times as high under short-circuit conditions as under transient conditions.

This requirement is fulfilled admirably by thyrite (see "Thyrite—A New Material for Lightning Arrestors," by K. B. McEachron, A.I.E.E. TRANS., v.50, 1930, p. 410–17) the characteristic equations of which are

$$\left.\begin{aligned} E &= KI^{1-n} \quad \text{or } \log E = \log K + (1-n)\log I \\ R &= KI^{-n} \quad \text{or } \log R = \log K - n \log I \end{aligned}\right\} \qquad (2)$$

in which I is the current, E the voltage, R the resistance, n a constant depending upon the ingredients, and K a constant depending upon the dimensions as well as the mixture. The exponent n varies in different mixtures, but for these reactor applications a value of 0.72 is used. From eqs 2 it is evident that K is the voltage drop across a given piece of thyrite when one ampere is flowing through it. It varies directly with the length L, and inversely with the 0.56 power of the diameter D and the 0.28 power of the cross section A of the piece; thus for a standard mixture

$$K = \frac{2{,}100\ L}{D^{0.56}} = \frac{1{,}960\ L}{A^{0.28}} \qquad (3)$$

The heating of thyrite under short time short-circuit conditions is based upon the assumption that all the heat is stored in the material. It is, for any time t,

$$Q = \alpha EIt = \alpha KI^{1.28}\,t = \frac{\alpha\, E^{4.57}\,t}{K^{3.57}} \qquad (4)$$

where α is the ratio of average to crest power during the cycle. Herefrom, if a voltage E_1 for time t_1 causes a temperature rise T (from test) then the voltage E that will cause the same temperature rise in time t is

$$E = \left(\frac{t_1}{t}\right)^{0.219} E_1 = \frac{1.884\ L}{t^{0.219}} \qquad (5)$$

from which a family of curves may be plotted for design purposes, as in Fig. 7.

Choice of a suitable thyrite shunt consists of: (1) determining the value of K that will give adequate impulse protection to the system; and (2) selecting a length and cross section for the thyrite unit that will have the desired value of K and at the same time be long enough to prevent overheating under short-circuit conditions. The possibilities are considered in detail in the next section of this paper.

Calculations

From the foregoing discussion of the circuit constants of the various units comprising a typical system employing reactors, it is evident that the equivalent circuit of such a system, with respect to impulses, is that of Fig. 2B. The feeder on which the incident wave approaches the bus hereafter is designated as the "incoming" line, while the other feeders are called "outgoing" lines. If the reactances in different feeders have different inductances, or other dissimilarity exists, then the solution to the circuit becomes very involved. However, if all feeders with their reactors and shunt resistors are alike, the solutions are relatively simple, the differential equations not exceeding the second order. In the Appendix these solutions are carried out in detail. Now the principal points of interest in these calculations are the maxima encountered. It so happens that the circuit constants in practical cases are of such magnitude that the capacitance becomes fully charged through the shunt resistor before any appreciable current flows through the reactor. On this account the maximum voltages, as well as the initial and final conditions, may be calculated ignoring the inductance. Referring to Fig. 3 it is seen that initially the voltages e_1, e_2, and e_3 are determined from the consideration that the bus capacitance acts like a short circuit and the inductances like open circuits. A little later the capacitance becomes fully charged, but the inductances still behave as open circuits; under this condition the voltage e_1 reaches its maximum. Then the inductances begin to take appreciable current, causing all 3 voltages eventually to reach the same final voltages, as determined by the conditions that the capacitance behaves as an open circuit while the inductances act as short circuits. That these limiting points as thus determined are essentially correct, may be verified by the complete solutions given in the Appendix and by the cathode ray oscillograms reproduced in this paper.

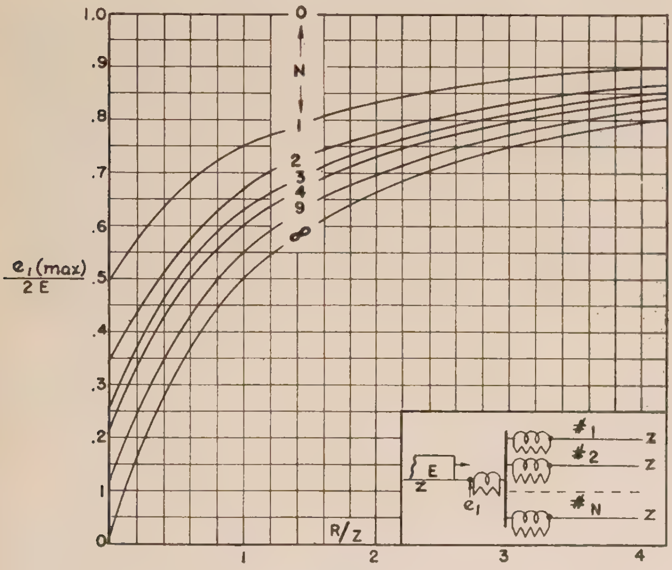
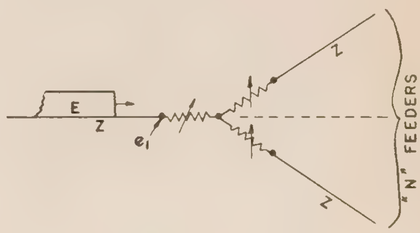


Fig. 4. Maximum voltage at reflection point; infinite rectangular applied wave

Figure 4 comprises a set of curves, based upon Fig. 3, giving the maximum value of e_1 as a function of the ratio of the shunt resistance of each reactor to the surge impedance of the line, and the number of outgoing feeders. These curves show that the greater the number of feeders, the lower the voltage at the reflection point, although the gain is not great for more than 6 feeders. The curves also show that the smaller R or the greater Z, the smaller the voltages at the reflection point. Therefore, a given shunt resistor will prove more effective for overhead line construction than for underground cables; or conversely, to realize the same advantages in either case, the resistance must be less for cable networks than for overhead lines. There is, however, another important point in this connection: Underground cable systems cannot be subjected to voltages greater than those caused by arcing grounds or switching surges, whereas overhead lines are exposed to much higher voltages due to lightning.

If thyrite resistors are used—and as already pointed out they are necessary—the circuit governing the conditions of maximum voltage is shown in Fig. 5; this circuit is solved in detail by the curves of Fig. 6.

Fig. 5. Circuit for calculating maximum voltages with thyrite



By means of these curves (for derivation of which see the Appendix) it is possible either to find the thyrite constant necessary to hold the voltage at the reflection point to any desired value; or conversely, to find what this voltage would be for a given thyrite constant. As an example, suppose that a certain 13.8-kv system is susceptible to impulse voltages of E = 50 kv, and that a thyrite shunt is to be found

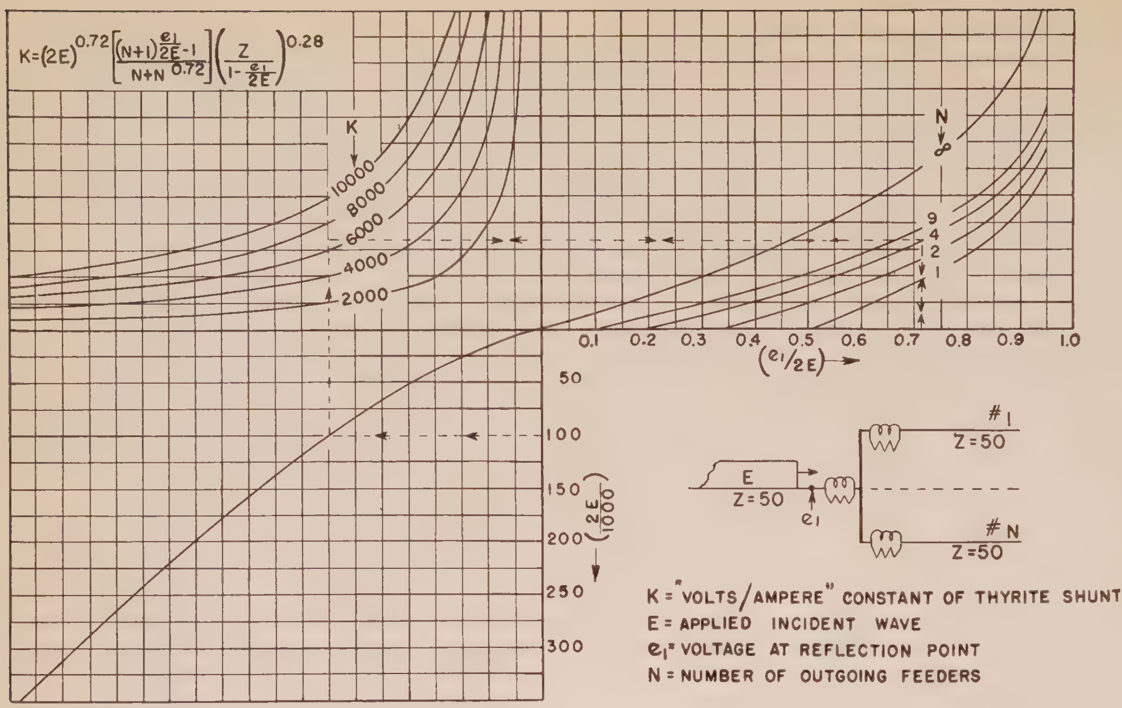


Fig. 6. Chart for calculating constants of thyrite shunt, or voltage at reflection point for a given shunt

such that the voltage at the reflection point will not exceed the insulation strength there of $e_1 = 70$ kv with 4 outgoing lines. Then entering the third quadrant of Fig. 6 at $2E = 100$ kv and the first quadrant at $e_1/2E = 0.70$ thence horizontally from the curve marked $N = 4$, it is seen that the 2 lines entering the second quadrant intersect on the $K = 6{,}600$ curve. This is the thyrite constant necessary to effect the specified requirements. So far as the impulse conditions are concerned, there are no restrictions on the dimensions of the thyrite piece having this constant; but the fact that the thyrite must stand a system short circuit for a fixed time decides the minimum length of the thyrite unit. In Fig. 7, the lower set of curves gives the necessary length of thyrite corresponding to the system voltage and the duration of short circuit. For a 13.8-kv system and a 10-sec short circuit, the minimum length is 7 in. Entering the upper set of curves at this length and at $K = 6{,}600$ shows that the nearest standard thyrite is (2) 3 in. in diameter. Thus the addition of 2 thyrite cylinders 3 in. in diameter by 7 in. long as a shunt for a current limiting reactor is instrumental in reducing the impulse voltage at the reflection point by 30 per cent; this resistor will not overheat on short circuit, nor otherwise interfere with operating conditions. In routine design of these shunt resistors, the necessity of using standard sizes of thyrite usually involves a certain amount of compromise; but in any event, reductions of impulse voltages of the order of 20 to 40 per cent are usually obtainable. From an engineering point of view the reduction should be enough to prevent a flashover at the reflection point, but if the insulation levels of the system and the impulse voltages to which they are subjected are not known definitely (which is usually the case) then the reduction, based upon switching surges, should be at least 25 per cent.

The equations of the Appendix enable one to calculate the effect of exponential incident waves, and hence, by superposition, waves compounded of exponential components, such as typical lightning waves with finite fronts and tails.

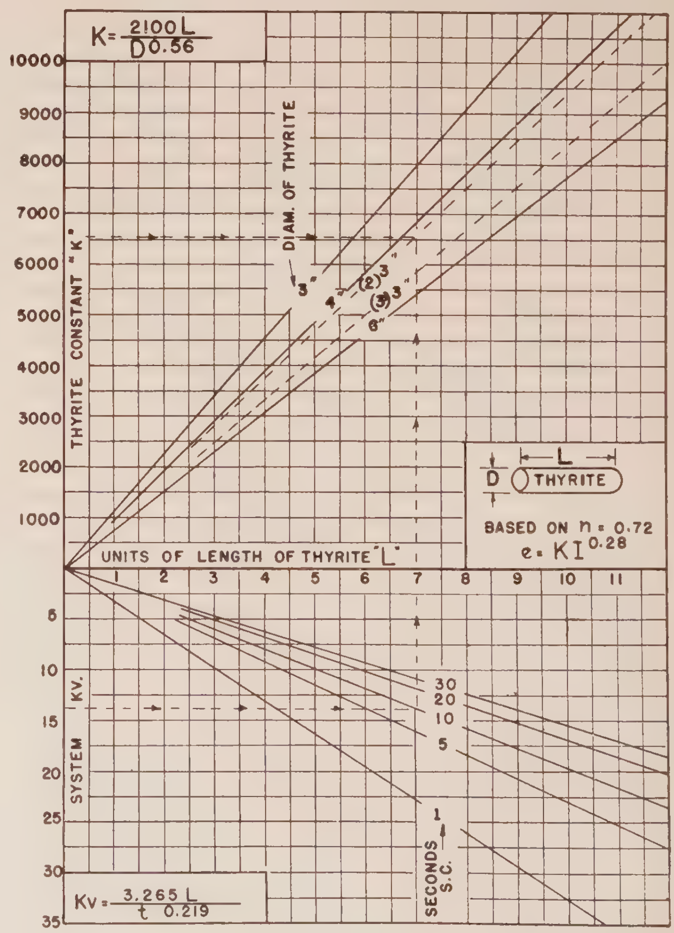
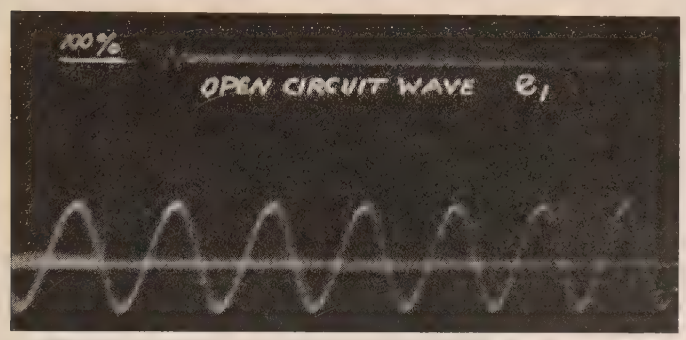


Fig. 7. Calculations of dimensions of thyrite shunt

Impulse Tests

In order to verify calculations pertaining to the circuit shown in Fig. 2A, impulse tests were made on the equivalent circuit shown in Fig. 2B. It has been shown mathematically, and by test, that the effect of an impulse upon a circuit is the same if it enters the circuit through a resistor as it would have been had it entered through a line or a cable, providing that the resistance of the resistor is the same as the surge impedance of the line or cable. It was permissible, therefore, to simplify the test circuit by replacing the incoming line with a resistor. Since reactors are used largely with underground cables having surge impedances of approximately 50 ohms, a resistor of 52 ohms was selected as the equivalent of the incoming cable. It is equally equivalent to replace the outgoing lines with a resistor, providing that the resistance of the resistor is made equal to the surge impedance of all the outgoing lines in parallel; therefore, the outgoing lines were replaced by resistors. Typical current limiting reactors were



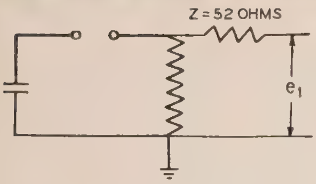


Fig. 8. Diagram of connections of impulse generator and wave form of open circuit voltage used in these tests (500,000-cycle timing wave)

used for the reactors. Capacitors were used to obtain the effect of the capacitance of the bus. The test circuits were as shown on Figs. 9, 10, 11, and 12.

Figure 8 shows the type of impulse employed in these tests. It may be noted that at the front of the wave there is an oscillation of very high frequency; this was inherent in the impulse generator circuit used and could not be eliminated. In order to make the comparisons between tests more definite, the axis of the oscillation is taken as the height of the wave.

On the oscillogram of Fig. 8, e_1 labelled 100% corresponds to a totally reflected incident wave of voltage E (in other words $e_1 = 2E$). That this is so is evident from the fact that if a surge impedance equal to Z_1 (52 ohms) be connected from Z_1 to the other terminal of the generator (which is the condition for no reflection) the value of e_1 would drop to E.

Tests were made on circuits corresponding to the following conditions:

Case I. An impulse entering a station having no other outgoing lines connected.

Case II. An impulse entering a station having 1 other outgoing line connected.

Case III. An impulse entering a station having 2 other outgoing lines connected.

Case IV. An impulse entering a station having 4 other outgoing lines connected.

In each case the tests were made (1) with no resistor shunting the reactor, (2) with a constant resistance of 52 ohms shunting the reactors, and (3)

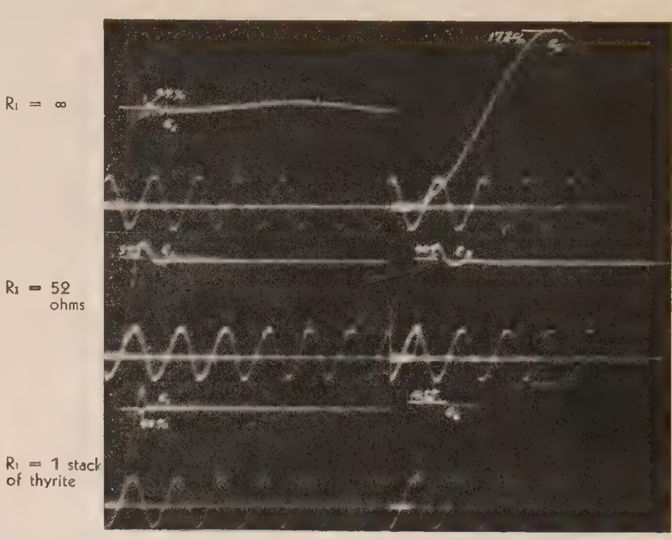
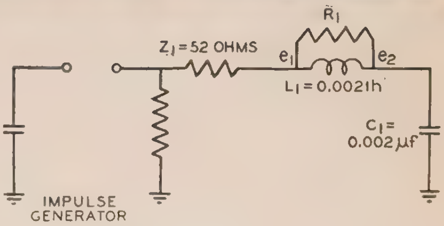
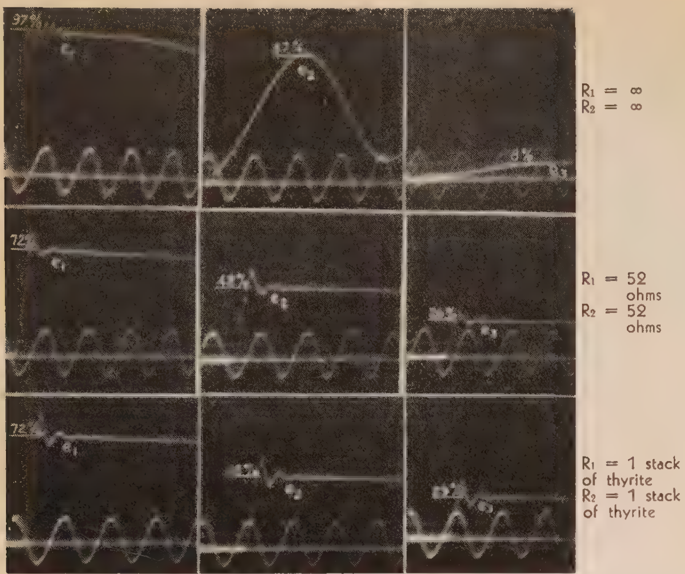


Fig. 9. Case I: test with no outgoing lines (500,000 - cycle timing wave)



with a stack of thyrite shunting the reactor. Voltages were measured at e_1, e_2, and e_3 (Fig. 2B) by a cathode ray oscillograph. A comparison of these tests shows in each case the effect of a constant shunt resistor on the impulse voltages and also the effect of thyrite.

Case I (Fig. 9). These tests correspond to an impulse entering a station that has no other outgoing feeders. The voltages at the reflection point and at the bus are higher than for any of the other cases, as should be expected. Thus when there was no shunt resistor the voltage e_1 was 0.99 ($2E$), which indicates almost complete reflection ($e_1 = 2E$ corresponds to complete reflection). The oscillation due to the passage of the impulse through the inductance L_1 into the capacitance C_1 causes the voltage e_2 to build up to 1.77 ($2E$). The addition of a constant shunt resistor of 52 ohms had no effect on the voltage e_1, but critically damped out the oscillation in the voltage e_2 reducing e_2 to 0.99 ($2E$), a reduction of 44 per cent. When the reactor was shunted by the thyrite resistor, the voltage e_1 again was unchanged. The oscillation in e_2 was almost entirely damped out, e_2 being 1.05 ($2E$), a reduction in voltage due to the thyrite of 41 per cent. This case does not represent practical operation because a bus seldom, if ever, would be operated with only one feeder connected. It is included for the sake of completeness.



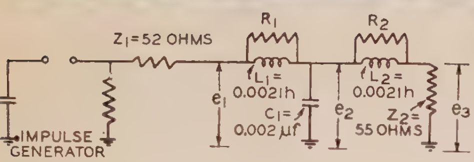
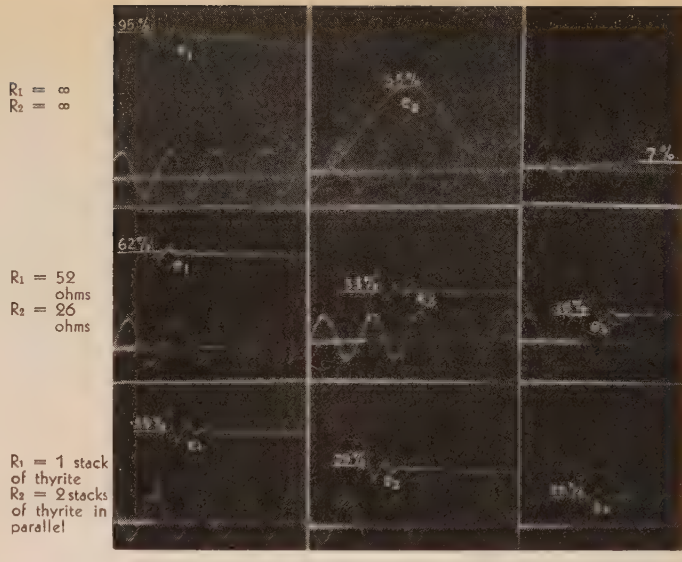


Fig. 10. Case II: test with one outgoing line (500,000 - cycle timing wave)



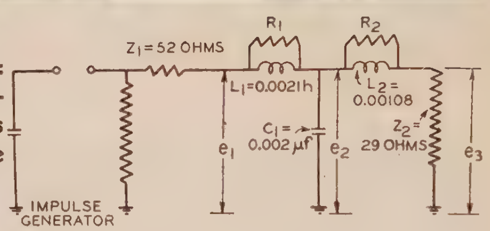


Fig. 11. Case III: test with 2 outgoing lines (500,000 - cycle timing wave)

Case II (Fig. 10). This test represents the condition of 2 feeders connected to the station bus with an impulse coming into the bus over one of them. The voltages e_1 and e_2 and the per cent reductions due to constant resistors and thyrite are given in the following table:

Resistors R_1	Resistors R_2	$\frac{e_1}{2E}$	Per Cent Reduction	$\frac{e_2}{2E}$	Per Cent Reduction
None	None	0.97		0.87	
52 ohms	52 ohms	0.72	26	0.48	45
1 Thyrite	1 Thyrite	0.72	26	0.48	45

Case III (Fig. 11). In these tests the circuit is equivalent to a bus with 3 connected feeders and an impulse coming in on one of them. The voltages e_1 and e_2 together with the per cent reduction due to constant resistors and thyrite are given in the following table:

Resistors R_1	Resistors R_2	$\frac{e_1}{2E}$	Per Cent Reduction	$\frac{e_2}{2E}$	Per Cent Reduction
None	None	0.95		0.55	
52	26	0.62	35	0.33	40
1 Thyrite	2 Thyrite	0.59	38	0.39	29

Case IV (Fig. 12). In these tests the circuit is approximately equivalent to a bus with 5 connected feeders. It is believed that this circuit more nearly represents operating conditions than the preceding ones. Occasions where a station would operate with less than 5 feeders connected to a bus are believed to be rare. The voltages e_1 and e_2 together with per cent reductions due to resistors and thyrite, are given in the following table:

Resistors R_1	Resistors R_2	$\frac{e_1}{2E}$	Per Cent Reduction	$\frac{e_2}{2E}$	Per Cent Reduction
None	None	0.96		0.39	
52	12	0.54	44	0.18	54
1 Thyrite	5 Thyrite	0.49	49	0.26	33

Comparison Between Calculations and Tests

In Table I is given a comparison between the tested and calculated voltages for all 4 cases. The agreement between the tests and calculations is well within the limits of testing accuracy. This close agreement demonstrates that the effect of thyrite shunt resistors on voltages caused by impulses can be calculated accurately by use of the formulas and curves given in this paper, and thus lends confidence to their use.

Appendix

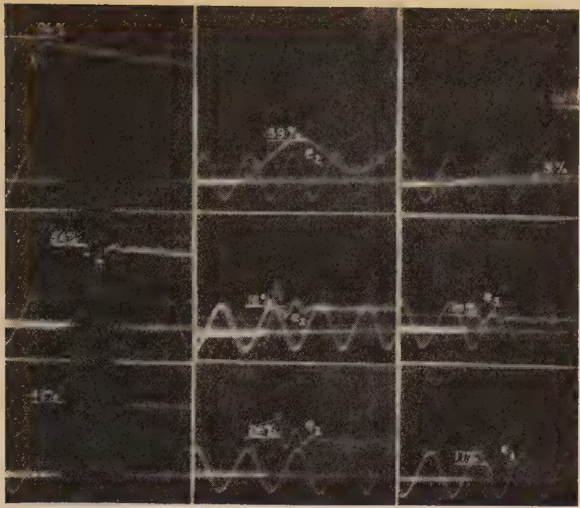
Referring to Fig. 2B, the operational equations for the 3 voltages e_1, e_2, and e_3 easily are verified to be:

$$e_2 = \frac{2E}{N+1}\frac{\omega_o^2}{\alpha}\left(\frac{p+\alpha}{p^2+2\beta p+\omega_o^2}\right)\epsilon^{\alpha t} \tag{6}$$

$$e_3 = \frac{\gamma}{\alpha}\left(\frac{p+\alpha}{p+\gamma}\right)e_2 \tag{7}$$

$$e_1 = 2E\epsilon^{-at} - \frac{\gamma}{\alpha}\left(\frac{p+\alpha}{p+\gamma}\right)(2E\epsilon^{-at} - e_2)$$

$$= (2E\epsilon^{-at} + e_3) - \frac{\gamma}{\alpha}\left(\frac{p+\alpha}{p+\gamma}\right)2E\epsilon^{-at} \tag{8}$$



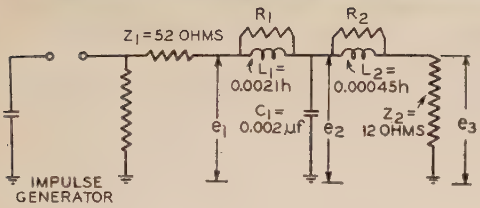


Fig. 12. Case IV: test with 4 outgoing lines (500,000 - cycle timing wave)

where

$$\left.\begin{aligned}
\alpha &= \frac{R}{L}\\
\beta &= \frac{(N+1)\,L + CRZ}{2LC\,(R+Z)}\\
\gamma &= \frac{RZ}{(R+Z)\,L}\\
\omega_o^2 &= \frac{(N+1)\,R}{LC\,(R+Z)}\\
E\epsilon^{-at} &= \text{applied incident wave}
\end{aligned}\right\} \tag{9}$$

Also let

$$\left.\begin{aligned}
\omega &= \sqrt{\omega_o^2 - \beta^2}\\
\sigma &= \beta + j\omega\\
\rho &= \beta - j\omega\\
A &= \frac{2E}{(N+1)}\,\frac{\omega_o^2}{\alpha}\left[\frac{\alpha - a}{\omega^2 + (\beta - a)^2}\right]\\
B &= \frac{\omega^2 + (\beta - \alpha)(\beta - a)}{\omega\,(\alpha - a)}\\
D &= \frac{\gamma}{\alpha}\left[\frac{\gamma - \alpha}{\gamma - a} - \frac{B\omega\,(\gamma - \alpha) + (\gamma - \beta)(\gamma - \alpha)}{(\gamma - \beta)^2 + \omega^2}\right]\\
G &= \frac{\gamma}{\alpha}\left[\frac{B\omega\,(\gamma - \alpha) - \omega^2 - (\alpha - \beta)(\gamma - \beta)}{(\gamma - \beta)^2 + \omega^2}\right]\\
H &= \frac{\gamma}{\alpha}\left[\frac{\omega\,(\gamma - \alpha) + \omega^2 B + (\alpha - \beta)(\gamma - \beta)B}{(\gamma - \beta)^2 + \omega^2}\right]
\end{aligned}\right\} \tag{10}$$

The solutions to eqs 6, 7, and 8 then are:

$$e_1 = e_3 + 2E\left(\frac{\gamma - \alpha}{\gamma - a}\right)\left(\frac{a\epsilon^{-at} - \gamma\epsilon^{-\gamma t}}{\alpha}\right) \tag{11}$$

$$e_2 = A\;\{\epsilon^{-at} + \epsilon^{-\beta t}\,[B\sin\omega t - \cos\omega t]\} \tag{12a}$$

$$= A\left\{\epsilon^{-at} - (1 + jB)\,\frac{\epsilon^{-\rho t}}{2} - (1 - jB)\,\frac{\epsilon^{-\sigma t}}{2}\right\} \tag{12b}$$

$$= A\,\{\epsilon^{-at} + \epsilon^{-\beta t}\,[\omega B t - 1]\}\ \text{ if } \omega = 0 \tag{12c}$$

Table I—Comparison of Calculated and Tested Voltages

Equivalent Number of Outgoing Lines	Shunt Resistor R_1	$\frac{e_1}{2E}$ Test	$\frac{e_1}{2E}$ Calc.	$\frac{e_2}{2E}$ Test	$\frac{e_2}{2E}$ Calc.
0	None	0.99		1.77	1.93
	52 ohms	0.99	1.00	0.99	1.00
	Thyrite	0.98	1.00	1.05	
1	None	0.97	1.00	0.87	0.97
	52 ohms	0.72	0.75	0.48	0.50
	Thyrite	0.72	0.70	0.48	0.51
1.8	None	0.95	1.00	0.55	
	52 ohms	0.62	0.68	0.33	0.35
	Thyrite	0.59	0.61	0.39	0.40
4.3	None	0.96	1.00	0.39	
	52 ohms	0.54	0.60	0.18	0.18
	Thyrite	0.49	0.48	0.26	0.26

$$e_3 = A\left\{\frac{\gamma}{\alpha}\left(\frac{\alpha - a}{\gamma - a}\right)\epsilon^{-at} + D\epsilon^{-\gamma t} + \epsilon^{-\beta t}\,(G\cos\omega + H\sin\omega t)\right\} \tag{13a}$$

$$= A\left\{\frac{\gamma}{\alpha}\left(\frac{\alpha - a}{\gamma - a}\right)\epsilon^{-at} + D\epsilon^{-\gamma t} + (G - jH)\frac{\epsilon^{-\rho t}}{2} + (G + jH)\,\frac{\epsilon^{-\sigma t}}{2}\right\} \tag{13b}$$

$$= A\left\{\frac{\gamma}{\alpha}\left(\frac{\alpha - a}{\gamma - a}\right)\epsilon^{-at} + D\epsilon^{-\gamma t} + \epsilon^{-\beta t}\,(G + \omega H t)\right\}\quad \text{if } \omega = 0 \tag{13c}$$

In the foregoing solutions, eqs 12a and 13a are for the oscillatory case; 12b and 13b for the nonoscillatory case; and 12c and 13c for the critically damped case. In the critically damped case $\omega = 0$, and therefore:

$$\left.\begin{aligned}
\omega B &= \frac{(\beta - \alpha)(\beta - a)}{(\alpha - a)}\\
D &= \frac{\gamma}{\alpha}\left[\frac{\gamma - \alpha}{\gamma - a} - \frac{(\beta - \alpha)(\beta - a)(\gamma - \alpha) + (\gamma - \beta)(\gamma - \alpha)(\alpha - a)}{(\alpha - a)(\gamma - \beta)^2}\right]\\
G &= \frac{\gamma}{\alpha}\left[\frac{(\beta - \alpha)(\beta - a)(\gamma - \alpha) - (\alpha - \beta)(\gamma - \beta)(\alpha - a)}{(\alpha - a)(\gamma - \beta)^2}\right]\\
\omega H &= \frac{\gamma}{\alpha}\left[\frac{-(\alpha - \beta)^2(\gamma - \beta)(\beta - a)}{(\alpha - a)\,(\gamma - \beta)^2}\right]
\end{aligned}\right\} \tag{14}$$

Criterion for Suppression of Oscillations

All oscillations will be suppressed if

$$\beta^2 > \omega_o^2 \tag{15}$$

Substituting from eq 9 there results

$$R < \left[\frac{(N+1)L}{ZC + 2\sqrt{(N+1)\,LC}}\right] < \frac{1}{2}\sqrt{(N+1)\,\frac{L}{C}} \tag{16}$$

In order to insure that the circuit will not oscillate under the most susceptible conditions, i. e., no outgoing feeders and zero surge impedance, the shunt resistor should be not more than

$$R_o = \frac{1}{2}\sqrt{\frac{L}{C}} \tag{17}$$

If this value of shunt resistance be used, then all possibility of oscillation vanishes, even in case of a line-to-ground sparkover at the line end terminal of the reactor.

Limiting Points

These equations give the characteristics of the transient, and serve to show why it is permissible, when shunt resistors are used, to determine the upper boundary of the transients from the following 3 limiting conditions:

(a). Initially the capacitance acts like a short circuit and the inductances like an open circuit, so that

$$e_1 = (2E)\left(\frac{R}{R+Z}\right) \qquad e_2 = 0 \qquad e_3 = 0$$

(b). The capacitance quickly charges in a few microseconds and then acts like an open circuit, but the inductances do not yet draw

an appreciable current, so that at this intermediate period

$$e_1 = (2E) \left\{ \frac{(N+1)R + Z}{(N+1)(R+Z)} \right\}$$

$$e_2 = \frac{(2E)}{(N+1)} \qquad e_3 = \frac{(Z)}{(R+Z)} \frac{(2E)}{(N+1)}$$

(c). Finally the inductances act like short circuits, and the fully charged capacitance like an open circuit, so that all 3 voltages approach equality

$$e_1 = e_2 = e_3 = \left(\frac{2E}{N+1}\right)$$

Determination of the Thyrite Shunt

A suitable thyrite shunt resistor must fulfill 3 requirements:

1. Under transient conditions the effective resistance must be low enough to render the circuit essentially nonoscillatory.

2. Under transient conditions the effective resistance must be low enough to limit the reflection to a safe value.

3. Under normal frequency conditions the effective resistance must be high enough to prohibit overheating of the resistor during a system short circuit.

It is evident from the oscillograms and from Fig. 3 that the maximum voltages occur when the capacitance first becomes fully charged, but before the inductances are carrying an appreciable current. The circuit then acts like a resistance circuit, in which the elements are the surge impedances of the lines (or cables) and the thyrite shunts. The voltage consumed by a thyrite resistor is $e = KI^{1-n}$ where the constants K and n are characteristic properties of the material; the constant K varies directly with the length of the thyrite stack, but the exponent n is independent of the dimensions and depends only on the material. An average value for the exponent is $n = 0.72$.

Rational design procedure for the thyrite shunt resistor consists in finding K such that the above transient conditions are met. The length and cross section of the thyrite stack then is selected so that for the required value of K the heating condition will not be violated.

Figure 5 represents the circuit at the period when the maximum reflection occurs. At the bus the current divides, each outgoing feeder carrying (I/N) amperes. Therefore

$$2E - ZI = KI^{1-n} + K\left(\frac{I}{N}\right)^{1-n} + Z\left(\frac{I}{N}\right) = e_1 \tag{18}$$

This equation may be solved either graphically or by a step by step method to determine the current I and hence e_1. Solving eq 18 for K there results

$$K = \left\{\frac{(N+1)e_1 - 2E}{(N+N^n)}\right\}\left(\frac{Z}{2E - e_1}\right)^{1-n} \tag{19}$$

where E is the maximum possible incident wave that can occur on the system and e_1 is the limit permitted at the reflection point. If E is fixed by the line insulation, then it is essential to prevent any positive reflection, for if a positive reflection occurs the insulation at the reflection point will break down. Therefore substituting $e_1 = E$ in eq 19 as the condition for no reflection there is

$$K = \frac{(N-1)E}{N+N^n}\left(\frac{Z}{E}\right)^{1-n} \quad \text{for no reflection} \tag{20}$$

The voltage at the bus is, in general,

$$e_2 = e_1 - KI^{1-n} = \frac{2E - (N^n - 1)e_1}{N + N^n} \tag{21}$$

The fewer the number of feeders the smaller must K be. Of course if there are no outgoing feeders the voltage at the reflection point will double, but the resistor will still be effective in preventing excessive oscillations to still higher values at the bus. One defect of a thyrite resistor is the fact that some oscillation always will occur if there are no outgoing feeders, because the final value of e_2 which comprises its axis of oscillation, is the same as e_1, and therefore each time that e_1 and e_2 approach equality, the voltage across the resistor approaches zero. However, the thyrite characteristic is such that its resistance is infinite when the voltage across it is zero. Hence it is helpless to exercise influence on the oscillation as e_2 passes through the critical value $e_2 = e_1$. Nevertheless, as soon as e_1 and e_2 part company the thyrite resistor becomes active in limiting the amplitude of oscillation.

Transients in Magnetic Systems

In the past, the solution of the transients in magnetic systems with solid cores has been carried out by assuming that the radial distribution of flux in other portions of the magnetic circuit is the same as in the solid portion. This paper presents a more precise mathematical analysis, the purpose of which is to determine the limits for which the foregoing assumption applies, and also to determine the nature of the phenomena for other cases in which that assumption is not permissible.

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THE MAGNETIC CIRCUIT in different types of equipment frequently consists of an air gap, a laminated iron part, and a solid iron part. When the field winding associated with a magnetic circuit of this character is energized by the application of a constant voltage, the eddy currents in the solid part of the core hinder the building up of the magnetic field. In the past, the treatment of this problem was carried out by assuming that the radial distribution of magnetic flux is the same in the air gap and laminated portion as in the solid portion. While for most cases this approximation is sufficiently accurate, it is desirable to obtain a more precise method to determine the limits for which this approximation applies and also to determine the nature of the phenomenon for the other cases in which this approximation is not permissible. In Fig. 1 the rectangle bounded by the heavy lines represents the solid part of the magnetic core. During the transient the eddy currents in the solid part of the core force most of the flux toward the outer edge. As the ends of the solid part are approached the flux lines curve tending to produce uniform distribution across the air gap and laminated portion. This is particularly true if the reluctance of the radial path of the flux be small compared with the reluctance of the air gap and laminated part. For the purpose of the present analysis the definite assumption will be made that the flux lines in the solid part are straight and that at the bound-

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ary ends of the solid part the flux lines can redistribute themselves without an radial drop in magnetomotive force. Thus the flux density in the air gap and laminated part is uniform, but in the solid part it is dependent upon the distribution of the eddy currents. This assumption is equivalent to inserting 2 disks of infinite permeability into the magnetic circuit at either end of the solid part as shown by the shaded areas of Fig. 2. This assumption implies that the radial component of magnetomotive force is small with respect to the component parallel to the axis. The analysis will follow along the general lines developed in an earlier paper (see "Field Transients in Magnetic Systems" by Ernst Weber, A.I.E.E. Trans., v. 50, 1931, p. 1234–46).

Problem and Results

With the foregoing fundamental assumption the flux and exciting current are determined as a constant voltage V is applied to the exciting winding shown in Fig. 2. The full development is given in the appendix; only sufficient data are given in the forepart of the paper to enable one to use and understand the results which are given in curve form.

The solid part of the core is assumed to be of circular cross section. The remainder of the magnetic circuit also is assumed to be of circular cross section of the same diameter; however, this is not essential as the remainder of the circuit always can be reduced to an equivalent one of the same reluctance, but having the diameter of the solid part.

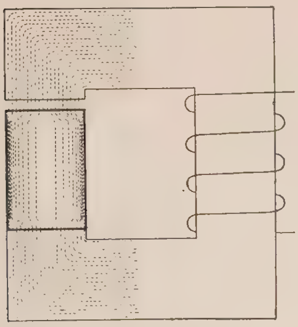

Fig. 1. Flux distribution in core as constant voltage is applied to exciting winding

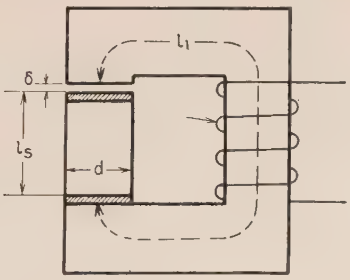

Fig. 2. Representation of magnetic circuit. Shaded portions represent disks of infinite permeability

The symbols indicated in Fig. 2 have the following significance:

d = diameter of solid part in centimeters
l_s = length of solid part in centimeters
δ = length of air gap in centimeters
l_l = length of laminated part in centimeters
ρ = resistivity of the solid part in ohms per cubic centimeter
N = number of turns in exciting winding
R = resistance of exciting winding in ohms
μ_l = permeability of laminated part
μ_s = permeability of solid part

For simplicity other auxiliary constants also are used. Since the flux distribution in both the air gap and the laminated portion is uniform, it is evident that an equivalent air gap can be used to represent both the actual air gap and the laminated portion. This equivalent air gap will be designated by a; its length will be

$$a = \delta + \frac{l_l}{\mu_l} \text{ centimeter} \tag{1}$$

A similar air gap can be used to represent the solid part of the iron for its magnetic properties, so that

$$b = \frac{l_s}{\mu_s} \text{ centimeter} \tag{2}$$

A convenient parameter for use in connection with the results is the fractional part, n, of the total magnetomotive force consumed in the solid part of the iron, thus

$$n = \frac{b}{a + b} \tag{3}$$

The self inductance of the exciting winding, neglecting leakage flux and eddy currents, is

$$L_o = \frac{(\pi d N)^2\, 10^{-9}}{a + b} \text{ henries} \tag{4}$$

The time constant of the exciting winding for the same conditions is designated

$$T_o = \frac{L_o}{R} \text{ seconds} \tag{5}$$

An additional parameter will appear in the development which, because it has a dimension of time and involves constants of the solid part of the core, will be called the core time constant and will be designated by T_s.

$$T_s = \frac{\pi}{10}\,\frac{\mu_s}{\rho}\, d^2 \text{ seconds} \tag{6}$$

Results of the mathematical analysis are plotted in curve form in Fig. 3. These curves show the instantaneous values of flux and exciting current as a fraction of their final or sustained values as a function of t/T_o for different values of n and T_s/T_o. An arbitrary value of leakage inductance associated with the exciting winding equal to 25 per cent of L_o was assumed in computing the curves.

Since the ordinates of the foregoing curves are expressed as a fraction of the final or sustained value, the actual values can be obtained from a knowledge of the sustained values which for the current is equal to V/R and for the flux $(VL_o/RN)10^8$.

Discussion of Results

From Fig. 3 it may be observed that for any value of n the flux lags more the larger T_s/T_o. The physical significance of this relation is evident from the fact that increasing T_s means decreasing ρ or increasing d^2, either one of which results in larger values of eddy currents.

The curves also show that for any given value of T_s/T_o the lag of the flux increases as n increases. From eqs 4, 5, and 6 it may be seen that

$$\frac{T_s}{T_o} = \frac{\mu_s R(a + b)}{10\pi\rho N^2} \tag{7}$$

Everything else remaining constant, as n increases, b must increase and a must decrease; thus the resistance of the eddy current path is decreased.

On the other hand the inductance of the eddy current path is not greatly affected by changing n so long as $(a + b)$ is constant. The net effect is that the eddy currents are larger and have a larger time constant, which delays the building up of the flux.

When n is equal to 1, the magnetic circuit consists of solid iron only. There being no radial component of flux, the assumptions upon which the analysis is based apply rigorously for this case. As n is decreased, the actual phenomenon departs more and more from the assumptions; but, as may be observed from the curves, more latitude is permissible in the fundamental data for a given accuracy in the results. The case in which $n = 1$, is also the only one for which the assumptions made by previous investigators apply. The results for this case are identical with those of Weber's (*loc. cit.*).

In his analysis Weber designates the individual curves by the symbol θ/T_o in which T_o is the same as in this paper, but θ is equal to nT_s. Thus for values of n differing from unity, it is only necessary to use the curve corresponding to the appropriate value of θ/T_s. The difference involved may be determined by comparing, for example, the curve for $n = 0.5$ and $T_s/T_o = 40$, which gives the results for the assumptions made in this paper, with the curve for $n = 1.0$ and $T_s/T_o = 20$, which gives the results for the assumptions made by Weber, namely, that the flux distribution in the air is the same as that in the iron. This comparison is as follows:

Time in Terms of $\frac{t}{T_o}$	A: $\frac{T_s}{T_o} = 40$, $n = 0.5$	B: $\frac{T_s}{T_o} = 20$, $n = 1.0$	$\frac{B}{A}$
1	0.320	0.280	0.875
2	0.503	0.450	0.895
3	0.615	0.575	0.935
4	0.694	0.665	0.958
5	0.753	0.737	0.979

It may be observed that the correspondence is quite close and will be still better for smaller values

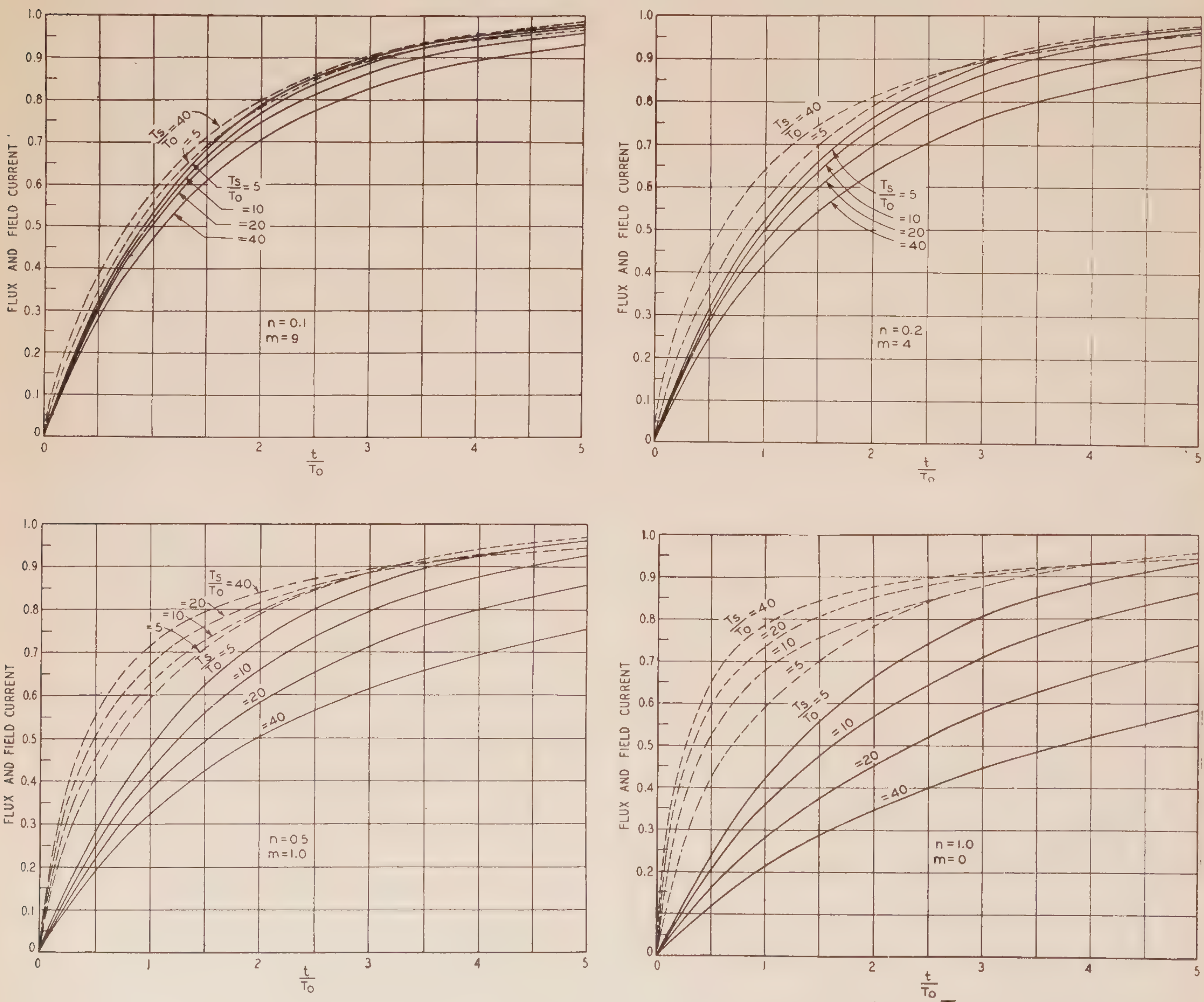

Fig. 3. Variation of total flux and field current as a function of $\frac{t}{T_o}$ and $\frac{T_s}{T_o}$

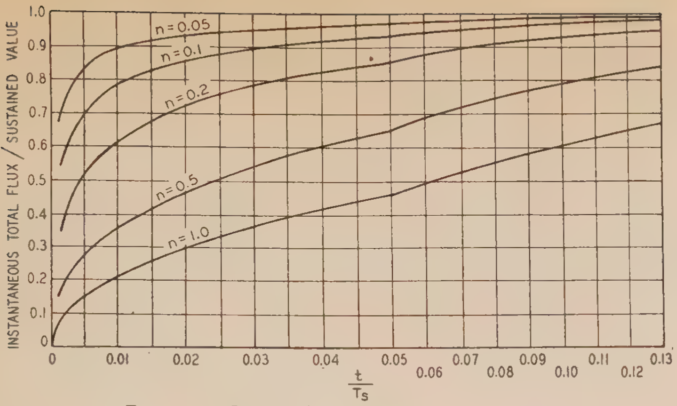

Fig. 4. Curves for total flux, $T_o = \infty$

of n and T_s/T_o, but will be worse for larger values of n and T_s/T_o.

Special Case for $T_o = \infty$

A particularly interesting case arises when $T_o = \infty$. Thus one might wish to know the character of the voltage of an alternator having a partially solid core for which the field current suddenly is interrupted. Because of the eddy currents in the solid part, the voltage cannot fall to zero instantly. The results for this case were obtained by letting $R = 0$, thus $T_o = 0$ and $T_s/T_o = \infty$. The transient components will be the same for suddenly removing and suddenly applying the voltage. The results for the case in which a voltage suddenly is applied to such a circuit are plotted in Fig. 4. For suddenly opening the field current the curves should be inverted, starting from unity instead of zero.

In this connection it is interesting to compare the results of this investigation with those obtained by R. Rudenberg (see "Elektrische Schaltvorgange," Julius Springer, Berlin, 1923, p. 70, 73, and 75). For the particular case for which Rudenberg's analysis is rigorous, *viz.*, when in the notation of this paper $n = 1$, he finds that when the core is of square cross section of d on a side the time constant of the fundamental component of the transient is $0.637\ (\mu s/\rho)d^2$ and the amplitude is 0.66. The results for the circular cross section of diameter d given in this paper for $n = 1$ give a time constant for the fundamental component equal to $0.543\ (\mu s/\rho)d^2$ and an amplitude equal to 0.69. Considering the greater volume of the core for the square cross section, the results agree quite closely.

Appendix

As stated previously, the analysis will follow quite closely that of Weber (*loc. cit.*), the fundamental difference being with regard to the assumption of uniform flux density in the air gap and laminated part. The practical system of units will be used, for example, centimeters, ohms, henries, and (magnetic) lines.

Fundamental Equations

The flux in the core can be resolved into 2 components: (1) that due to the exciting or field winding, and (2) that due to the induced eddy currents in the solid part of the core.

Flux Due to Exciting Winding. This flux circulates through the entire magnetic circuit and has a uniform density, B_1, across the section; it is a function of time only. The line integral of flux density is related to the exciting current of the field by the following equation:

$$\left(\frac{l_s}{\mu_s} + \frac{l_l}{\mu_l} + \delta\right) B_1 = \frac{4\pi}{10} Ni$$

or

$$B_1 = K_1 i \quad \text{gausses} \tag{8}$$

in which

i = instantaneous value of field current
N = number of turns in field current

$$K_1 = \frac{4\pi 10^{-1} N}{\dfrac{l_s}{\mu_s} + \dfrac{l_l}{\mu_l} + \delta} \tag{9}$$

Flux Due to Eddy Currents. The flux density due to the eddy currents is designated B_2 and is a function of both time and radius. Let G be the current density at any point in the solid part of the iron as shown in Fig. 5. The total current enclosed in the incremental area shown is l_sGdr. The current enclosed by this area times 0.4π must be equal to the line integral of the magnetomotive force about it. On the inner side the contribution to the line integral is $\frac{l_s}{\mu_s} B_2$ and on the outer side $\frac{l_s}{\mu_s}\left(B_2 + \frac{\partial B_2}{\partial r} dr\right)$. The ends contribute nothing because the integral passes through material which by assumption has infinite permeability. Then

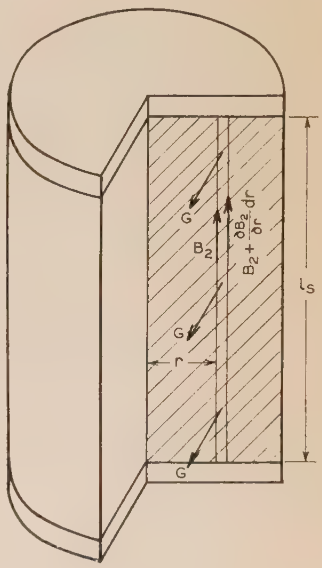

Fig. 5. Solid part of core

$$\frac{l_s}{\mu_s} B_2 - \frac{l_s}{\mu_s}\left(B_2 + \frac{\partial B_2}{\partial r} dr\right) = 0.4\pi l_s G dr$$

or

$$\frac{\partial B_2}{\partial r} = -0.4\pi\mu_s G \quad \text{gausses per centimeter} \tag{10}$$

The eddy currents are produced by the time rate of change of the flux encircling any point, thus

$$\int \rho G d_s = -10^{-8} \frac{\partial}{\partial t}\int\int (B_1 + B_2) dA$$

$$2\pi r \rho G = -10^{-8} \frac{\partial}{\partial t}\int 2\pi r (B_1 + B_2) dr$$

$$r\rho G = -10^{-8} \frac{\partial}{\partial t}\int r(B_1 + B_2) dr$$

Differentiating with respect to r

$$r\frac{\partial G}{\partial r} + G = -10^{-8} \frac{r}{\rho}\frac{\partial}{\partial t}(B_1 + B_2) \tag{11}$$

The total flux, ϕ_t, flows through both the solid part and the air gap, but with different radial distribution in the 2 parts. This flux is

$$\phi_t = \int\int (B_1 + B_2) dA$$

and since B_1 is uniform over the section

$$\phi_t = \frac{\pi d^2}{4} B_1 + 2\pi \int_0^{\frac{d}{2}} r B_2 dr \tag{12}$$

The following voltage equation may be written for the exciting winding

$$Ri + S\frac{di}{dt} + 10^{-8} N \frac{d\phi_t}{dt} = V \text{ in volts} \tag{13}$$

where S is the leakage inductance of the exciting winding.

Equations 8, 10, 11, 12, and 13 constitute the mathematical statement of the problem.

From eq 10

$$\frac{\partial G}{\partial r} = -\frac{1}{0.4\pi\mu_s}\frac{\partial^2 B_2}{\partial r^2} \tag{14}$$

After substituting $\frac{\partial G}{\partial r}$ from eq 14 and G from eq 10 into eq 11, there results

$$\frac{\partial^2 B_2}{\partial r^2} + \frac{1}{r}\frac{\partial B_2}{\partial r} = \frac{4\pi 10^{-9}\mu_s}{\rho}\frac{\partial}{\partial t}(B_1 + B_2) \tag{15}$$

Equation 13 may be rewritten using the notation of the Heaviside operational calculus. Heaviside's unit function will be denoted by a bold face numeral **1**.

$$(R + pS)i + p\,10^{-8} N\phi_t = V\cdot\mathbf{1} \tag{16}$$

Substituting eq 12

$$(R + pS)i + p\frac{\pi d^2 10^{-8}}{4} NB_1 = V\cdot\mathbf{1} - 2\pi 10^{-8} Np\int_0^{\frac{d}{2}} rB_2 dr \tag{17}$$

Replacing B_1 by its value from eq 8

$$\left(R + pS + p\frac{\pi}{4}k_1 Nd^2 10^{-8}\right)i = V\cdot\mathbf{1} - 2\pi 10^{-8} Np\int_0^{\frac{d}{2}} rB_2 dr \tag{18}$$

From eq 8, the total flux due to i is $\frac{\pi d^2}{4}B_1$ or $\frac{\pi d^2}{4}k_1 i$, so that defining L_o as the self inductance of the exciting winding, neglecting leakage,

$$L_o = \frac{\pi}{4}k_1 Nd^2 10^{-8} \text{ henries} \tag{19}$$

After substituting eq 19, eq 18 becomes

$$(R + pS + pL_o)i = V\cdot\mathbf{1} - 2\pi 10^{-8} Np\int_0^{\frac{d}{2}} rB_2\, dr \tag{20}$$

from which

$$i = \frac{V\cdot\mathbf{1} - 2\pi 10^{-8} Np\int_o^{\frac{d}{2}} rB_2 dr}{R + pS + pL_o} \tag{21}$$

The denominator may be designated conveniently by P so that

$$P = R + pS + pL_o \tag{22}$$

and eq 20 becomes

$$i = \frac{V}{P}\cdot\mathbf{1} - \frac{2\pi 10^{-8} Np}{P}\int_0^{\frac{d}{2}} rB_2 dr \tag{23}$$

From eqs 8 and 23

$$B_1 = \frac{k_1 V}{P}\cdot\mathbf{1} - \frac{2\pi 10^{-8} k_1 Np}{P}\int_0^{\frac{d}{2}} rB_2 dr \tag{24}$$

Now returning to eq 15, by converting to the Heaviside notation

$$\frac{\partial^2 B_2}{\partial r^2} + \frac{1}{r}\frac{\partial B_2}{\partial r} - \frac{4\pi 10^{-9}\mu_s}{\rho}pB_2 = \frac{4\pi 10^{-9}\mu_s}{\rho}pB_1 \tag{25}$$

and after substituting eq 24

$$\frac{\partial^2 B_2}{\partial r^2} + \frac{1}{r}\frac{\partial B_2}{\partial r} - \frac{4\pi 10^{-9}\mu_s}{\rho}pB_2 =$$

$$\frac{4\pi 10^{-9}\mu_s}{\rho}p\left[\frac{k_1}{P}V\cdot\mathbf{1} - \frac{2\pi 10^{-8} k_1 N}{P}p\int_0^{\frac{d}{2}} rB_2 dr\right] \tag{26}$$

It may be observed that the left hand side of eq 26 is a differential equation in r and that the right hand side is independent of r. It follows that the solution consists of the sum of the solution for the homogeneous differential equation

$$\frac{\partial^2 B_2}{\partial r^2} + \frac{1}{r}\frac{\partial B_2}{\partial r} - \frac{4\pi 10^{-9}\mu_s}{\rho}pB_2 = 0 \tag{27}$$

which will be designated by B_2' and a particular integral of eq 25 which will be designated by B_2''. The solution for eq 27 is given in terms of Bessel's functions of the first order and of the first 2 kinds. Thus

$$B_2' = CJ_o(kr) + DN_o(kr) \tag{28}$$

in which C and D are arbitrary constants of integration, in which

$$k = \sqrt{-\frac{4\pi 10^{-9}\mu_s}{\rho}p} \tag{29}$$

The particular integral may be assumed to be

$$B_2'' = F(p) \tag{30}$$

Therefore

$$B_2 = B_2' + B_2'' = CJ_o(kr) + DK_o(kr) + F(p) \tag{31}$$

The integration constants will be determined next. At $r = 0$ the density of the eddy currents is zero, so that placing $G = 0$ in eq 10,

$$\frac{\partial B_2}{\partial r} = 0 \tag{32}$$

Differentiating eq 31 with respect to r

$$\frac{dB_2}{dr} = -C(kr)J_1(kr) - D(kr)N_1(kr) \tag{33}$$

The $F(p)$ drops out because its differential with respect to r is zero. Now letting $kr = 0$ in eq 33

$$J_1(kr) = 0$$

$$(kr)N_1(kr) = -1$$

so that, since $\frac{dB_2}{dr} = 0$,

$$D = 0 \tag{34}$$

Therefore,

$$B_2 = CJ_o(kr) + F(p) \tag{35}$$

To determine the constant C, the value of B_2 will be determined for $r = d/2$. Taking the line integral of magnetomotive force along a path for $r = d/2$ in the solid part, and continuing through the air gap and laminated part to form a closed loop, since no current is enclosed, the integrals must be equal to zero. There results then that

$$\frac{l_s}{\mu_s}B_2\Big|_{r=\frac{d}{2}} + \left(\delta + \frac{l_l}{\mu_l}\right)B_a = 0 \tag{36}$$

in which B_a is the flux density in the air gap and laminated iron. B_a is also equal to the average flux density in the solid part of the iron, that is

$$B_a = \frac{4}{\pi d^2}\int\int B_2\, dA$$

$$= \frac{4}{\pi d^2}2\pi\int_0^{\frac{d}{2}} B_2 r dr$$

and substituting eq 35

$$B_a = \frac{8}{d^2}\int_0^{\frac{d}{2}}\left[CJ_o(kr) + F(p)\right] rdr$$

$$= \frac{8}{d^2}C\int_0^{\frac{d}{2}} J_o(kr)rdr + \frac{8}{d^2}F(p)\int_0^{\frac{d}{2}} rdr$$

$$= \frac{8}{d^2}C\int_0^{\frac{d}{2}} J_o(kr)r\, dr + F(p) \tag{37}$$

But

$$\int_0^{\frac{d}{2}} J_o(kr)r\,dr = \frac{d}{2k}\,J_1\left(\frac{kd}{2}\right) \tag{38}$$

After substituting eq 38 in eq 37

$$B_a = \frac{4}{kd}\,CJ_1\left(\frac{kd}{2}\right) + F(p) \tag{39}$$

After inserting $d/2$ for r in eq 35 and then substituting this value of eq 35 and also 39 in 36

$$\frac{l_s}{\mu_s}\left[CJ_o\left(\frac{kd}{2}\right) + F(p)\right] + \left(\delta + \frac{l_l}{\mu_l}\right)\left[\frac{4}{kd}\,CJ_1\left(\frac{kd}{2}\right) + F(p)\right] = 0 \tag{40}$$

Solving for C

$$C = -\frac{\left(\delta + \frac{l_l}{\mu_l} + \frac{l_s}{\mu_s}\right)}{\frac{l_s}{\mu_s}\,J_o\left(\frac{kd}{2}\right) + \left(\delta + \frac{l_l}{\mu_l}\right)\frac{4}{kd}\,J_1\left(\frac{kd}{2}\right)}\,F(p) \tag{41}$$

The notation may be simplified by inserting the a and b quantities defined in the body of the paper.

$$C = -\frac{a+b}{bJ_o\left(\frac{kd}{2}\right) + a\,\frac{4}{kd}\,J_1\left(\frac{kd}{2}\right)}\,F(p) \tag{42}$$

Substitute eq 42 in eq 35

$$B_2 = F(p) - \frac{(a+b)J_o(kr)}{bJ_o\left(\frac{kd}{2}\right) + a\left(\frac{4}{kd}\right)J_1\left(\frac{kd}{2}\right)}\,F(p) \tag{43}$$

Taking stock, a solution of B_2 has been found in operational form which must satisfy the fundamental equation (26). It may be recalled from eqs 30 and 31 that

$$B_2 = F(p) + B_2'$$

in which B_2' now represents the second part of eq 43. Since B_2' was obtained by solving eq 27, on substituting it back into the left hand member of eq 26 it will be equal to zero and, therefore, may be neglected. It remains only necessary, therefore, to substitute $F(p)$ into the left hand member and B_2 into the right hand member. When differentiated with respect to r, $F(p)$ is zero and the left hand member becomes $-\frac{4\pi\,10^{-9}\,\mu_s}{\rho}\,p\,F(p)$.

Substitution into the right hand member involves the determination of $\int_0^{\frac{d}{2}} r\,B_2\,dr$

$$\int_0^{\frac{d}{2}} rB_2dr = F(p)\int_0^{\frac{d}{2}} rdr - F(p)\,\frac{a+b}{bJ_o\left(\frac{kd}{2}\right) + a\,\frac{4}{kd}\,J_1\left(\frac{kd}{2}\right)}\int_0^{\frac{d}{2}} rJ_o(kr)dr$$

The expression for the second integral of the right hand member is given by eq 38, so that

$$\int_0^{\frac{d}{2}} rB_2dr = \frac{d^2}{8}\,F(p) - \frac{\frac{d}{2k}\,(a+b)\,J_1\left(\frac{kd}{2}\right)}{bJ_o\left(\frac{kd}{2}\right) + a\,\frac{4}{kd}\,J_1\left(\frac{kd}{2}\right)}\,F(p)$$

$$= F(p)\,\frac{d^2}{8}\left[1 - \frac{2\,(a+b)J_1\left(\frac{kd}{2}\right)}{\left(\frac{kd}{2}\right)\,bJ_o\left(\frac{kd}{2}\right) + 2aJ_1\left(\frac{kd}{2}\right)}\right] \tag{44}$$

Equation 26 then becomes, after substituting eq 44,

$$-\frac{4\pi10^{-9}\mu_s}{\rho}\,pF(p) = \frac{4\pi10^{-9}\mu_s}{\rho}\,p\left\{\frac{K_1}{P}\,V\cdot\mathbf{1} - \frac{2\pi10^{-8}K_1N}{P}\,\frac{d^2}{8}\,F(p)p\left[1 - \frac{2(a+b)J_1\left(\frac{kd}{2}\right)}{\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right) + 2aJ_1\left(\frac{kd}{2}\right)}\right]\right\}$$

or

$$F(p) = \frac{V}{\frac{P}{K_1}\left[\frac{\pi10^{-8}NK_1d^2}{4P}\,p\left\{1 - \frac{2(a+b)J_1\left(\frac{kd}{2}\right)}{\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right) + 2aJ_1\left(\frac{kd}{2}\right)}\right\} - 1\right]}\cdot\mathbf{1}$$

and substituting L_o from eq 19

$$F(p) = \frac{K_1V}{L_op\left\{1 - \frac{2(a+b)J_1\left(\frac{kd}{2}\right)}{\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right) + 2aJ_1\left(\frac{kd}{2}\right)}\right\} - P}\cdot\mathbf{1} \tag{45}$$

Now substituting eq 45 in eq 43

$$B_2 = \frac{\left[1 - \frac{(a+b)J_o(kr)}{bJ_o\left(\frac{kd}{2}\right) + 2a\left(\frac{2}{kd}\right)J_1\left(\frac{kd}{2}\right)}\right]K_1V}{L_op\left[1 - \frac{2\,(a+b)J_1\left(\frac{kd}{2}\right)}{\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right) + 2aJ_1\left(\frac{kd}{2}\right)}\right] - P}\cdot\mathbf{1}$$

But $P = R + P(S + L_o)$, so that

$$B_2 = \frac{\left[\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right) + 2aJ_1\left(\frac{kd}{2}\right) - (a+b)\left(\frac{kd}{2}\right)J_o(kr)\right]K_1V}{L_op\left[\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right) - 2bJ_1\left(\frac{kd}{2}\right)\right] - \left[R + p(S+L_o)\right]\left[\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right) + 2aJ_1\left(\frac{kd}{2}\right)\right]}\cdot\mathbf{1} \tag{46}$$

Equation 46 provides a solution of B_2 in operational form. A corresponding solution for i and ϕ_t will be obtained next. Equation 23 will be used to obtain i, but it will be necessary to obtain first the integral that appears in that expression. Substituting eq 45 in eq 44

$$\int_0^{\frac{d}{2}} rB_2dr = \frac{\frac{d^2}{8}\left[1 - \frac{2(a+b)J_1\left(\frac{kd}{2}\right)}{\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right) + 2aJ_1\left(\frac{kd}{2}\right)}\right]K_1V}{L_op\left[1 - \frac{2(a+b)J\left(\frac{kd}{2}\right)}{\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right) + 2aJ_1\left(\frac{kd}{2}\right)}\right] - P}\cdot\mathbf{1}$$

$$= \frac{d^2}{8}\,\frac{\left[\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right) - 2bJ_1\left(\frac{kd}{2}\right)\right]K_1V}{L_op\left[\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right) - 2bJ_1\left(\frac{kd}{2}\right)\right] - P\left[\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right) + 2aJ_1\left(\frac{kd}{2}\right)\right]}\cdot\mathbf{1} \tag{47}$$

Substituting eq 47 in eq 23

$$i = \frac{V}{P}\left\{1 - \frac{2\pi10^{-8}NPd^2K_1}{8}\,\frac{\left[\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right) - 2bJ_1\left(\frac{kd}{2}\right)\right]}{L_op\left[\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right) - 2bJ_1\left(\frac{kd}{2}\right)\right] - P\left[\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right) + 2aJ_1\left(\frac{kd}{2}\right)\right]}\cdot\mathbf{1}\right.$$

But since $\frac{\pi10^{-8}Nd^2K_1}{4} = L_o$ from eq 19, then

$$i = -\frac{\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right) + 2aJ_1\left(\frac{kd}{2}\right)}{L_op\left[\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right) - 2bJ_1\left(\frac{kd}{2}\right)\right] - P\left[\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right) + 2aJ_1\left(\frac{kd}{2}\right)\right]}\,V\cdot\mathbf{1} \tag{48}$$

The operational form for ϕ_t can be obtained by substituting B_1 from eq 8, i from eq 48, and $\int_0^{\frac{d}{2}} r\,B_2\,dr$ from eq 47 into eq 12 giving

$$\phi_t = \frac{-\frac{\pi d^2}{4}K_1\left[\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right)+2aJ_1\left(\frac{kd}{2}\right)\right] + \frac{\pi d^2 K_1}{4}\left[\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right)-2bJ_1\left(\frac{kd}{2}\right)\right]}{L_o p\left[\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right)-2bJ_1\left(\frac{kd}{2}\right)\right] - P\left[\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right)+2aJ_1\left(\frac{kd}{2}\right)\right]}V\cdot 1$$

and since $\frac{\pi d^2}{4}K_1 = \frac{L_o}{N}10^8$

$$\phi_t = -\frac{2\times 10^8\frac{L_o}{N}(a+b)J_1\left(\frac{kd}{2}\right)V}{L_o p\left[\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right)-2bJ_1\left(\frac{kd}{2}\right)\right] - P\left[\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right)+2aJ_1\left(\frac{kd}{2}\right)\right]}.1 \qquad (49)$$

The solutions for B_2, i, and ϕ_t now are expressed in operational form and may be written

$$B_2 = \frac{Y_2(p)}{Z(p)}V\cdot 1 \qquad (50)$$

$$i = \frac{Y_i(p)}{Z(p)}V\cdot 1 \qquad (51)$$

$$\phi_t = \frac{Y\phi(p)}{Z(p)}V\cdot 1 \qquad (52)$$

in which

$$Y_2(p) = K_1\left[b\left(\frac{kd}{2}\right)J_o\left(\frac{kd}{2}\right) + 2aJ_1\left(\frac{kd}{2}\right) - (a+b)\left(\frac{kd}{2}\right)J_o(kr)\right] \qquad (53)$$

$$Y_i(p) = -\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right) - 2aJ_1\left(\frac{kd}{2}\right) \qquad (54)$$

$$Y\phi(p) = -2\times 10^8\frac{L_o}{N}(a+b)J_1\left(\frac{kd}{2}\right) \qquad (55)$$

$$Z(p) = L_o p\left[\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right)-2bJ_1\left(\frac{kd}{2}\right)\right] - [R+p(S+L_o)]\left[\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right)+2aJ_1\left(\frac{kd}{2}\right)\right] \qquad (56)$$

By the application of the Heaviside expansion theorem

$$B_2 = \frac{Y_2(o)}{Z(o)}V + V\sum_1^\infty\left[\frac{Y_2(p)}{p\frac{d}{dp}(Zp)}\epsilon^{p_\nu t}\right]_{p=p_\nu} \qquad (57)$$

where the values of p_ν are the roots of $Z(p)$. Similarly

$$i = \frac{Y_i(o)}{Z(o)}V + V\sum_1^\infty\left[\frac{Y_i(p)}{p\frac{d}{dp}Z(p)}\epsilon^{p_\nu t}\right]_{p=p_\nu} \qquad (58)$$

and

$$\phi_t = \frac{Y\phi(o)}{Z(o)}V + V\sum_1^\infty\left[\frac{Y\phi(p)}{p\frac{d}{dp}Z(p)}\epsilon^{p_\nu t}\right]_{p=p_\nu} \qquad (59)$$

The next step involves the determination of the roots of $Z(p)$ which may be rewritten, collecting terms,

$$Z(p) = -(R+pS)\left(\frac{kd}{2}\right)bJ_o\left(\frac{kd}{2}\right) - 2(bL_o p + Ra + paS + paL_o)J_1\left(\frac{kd}{2}\right) \qquad (60)$$

Letting $\frac{kd}{2} = q$, from eq 29

$$q = \frac{kd}{2} = \sqrt{-\frac{\pi 10^{-9}\mu_s d^2}{\rho}p} \qquad (61)$$

or

$$q^2 = -\frac{\pi 10^{-9}\mu_s d^2}{\rho}p = T_s p \qquad (62)$$

in which

$$T_s = \frac{\pi 10^{-9}\mu_s d^2}{\rho}\text{ seconds} \qquad (63)$$

This quantity has the dimension of time and determines the lag of the phenomenon due to the eddy currents. Also

$$p = -\frac{q^2}{T_s} \qquad (64)$$

After substituting eqs 61 and 64 in eq 56, $Z(p)$ becomes

$$Z(p) = -\left(R - \frac{q^2}{T_s}S\right)qbJ_o(q) - 2\left[aR - \frac{q^2}{T_s}(bL_o + aL_o + aS)\right]J_1(q)$$

Now let

$$\sigma = \frac{S}{L_o} \qquad (65)$$

This is a fraction which expresses the leakage associated with the exciting winding in terms of the self-inductance of the exciting winding.

Also let

$$T_o = \frac{L_o}{R}\text{ seconds} \qquad (66)$$

which is defined in the body of the paper, and

$$m = \frac{a}{b} \qquad (67)$$

Then substituting these quantities in the expression for $Z(p)$,

$$Z(p) = -\frac{L_o b}{T_s}\left\{\left(\frac{T_s}{T_o} - \sigma q^2\right)qJ_o(q) + 2\left[m\frac{T_s}{T_o} - q^2(1+m+m\sigma)\right]J_1(q)\right\} \qquad (68)$$

To obtain the roots, q_1, q_2, q_3, etc., transform to

$$\frac{J_o(q)}{J_1(q)} = -\frac{2\left[m\frac{T_s}{T_o} - q^2(1+m+m\sigma)\right]}{\left[\frac{T_s}{T_o} - \sigma q^2\right]q} \qquad (69)$$

This is most readily solved by a graphical method, plotting the left hand and right hand members and determining the intersections of the resulting curves.

The denominator of eqs 57 to 59, $p\frac{d}{dp}Z(p)$, being a function of p must be evaluated and expressed as a function of q.

$$p\frac{d}{dp}Z(p) = -\frac{q^2}{T_s}\frac{dq}{dp}\frac{d}{dq}Z(p) \qquad (70)$$

Differentiating eq 68

$$\frac{d}{dq}Z(p) = -\frac{L_o b}{T_s}\left\{\left(\frac{T_s}{T_o} - 3\sigma q^2\right)J_o(q) - \left(\frac{T_s}{T_o} - \sigma q^2\right)qJ_1(q) - 4q(1+m+m\sigma)J_1(q) + 2\left[\frac{T_s}{T_o}m - q^2(1+m+m\sigma)\right]\left[J_o(q) - \frac{1}{q}J_1(q)\right]\right\}$$

$$= -\frac{L_o b}{T_s}\left\{\left[\frac{T_s}{T_o}(1+2m) - 2(1+m+m\sigma)q^2 - 3\sigma q^2\right]J_o(q) - \left[\frac{T_s}{T_o}\left(q + \frac{2m}{q}\right) - \sigma q^3 + 2(1+m+m\sigma)q\right]J_1(q)\right\} \qquad (71)$$

From eq 64

$$\frac{dq}{dp} = -\frac{T_s}{2q} \tag{72}$$

so that inserting eqs 71 and 72, eq 70 becomes

$$p\frac{d}{dp}Z(p) = -q\frac{L_o b}{2T_s}\left\{\left[\frac{T_s}{T_o}(1+2m) - 2(1+m+m\sigma)q^2 - 3\sigma q^2\right]J_o(q) - \left[\frac{T_s}{T_o}\left(q+\frac{2m}{q}\right) - \sigma q^3 + 2(1+m+m\sigma)q\right]J_1(q)\right\} \tag{73}$$

The numerators of eqs 57 to 59 may be obtained in terms of q by inserting eqs 65, 66, and 67 in eqs 53 to 55, giving

$$Y_2(p) = bK_1\left[qJ_o(q) + 2mJ_1(q) - (1+m)qJ_o\left(\frac{2qr}{d}\right)\right] \tag{74}$$

$$Y_1(p) = -b[qJ_o(q) + 2mJ_1(q)] \tag{75}$$

$$Y\phi(p) = -\frac{2\times 10^8 bL_o(1+m)}{N}J_1(q) \tag{76}$$

There remains yet to determine the first terms of eqs 57 to 59. Since $q = 0$ when $p = 0$, $\frac{Y_2(o)}{Z(o)}$ can be determined by letting $q = 0$ in eqs 74 and 68. As q approaches zero $J_o(q)$ approaches unity and $J_1(q)$ approaches $q/2$, so that

$$\frac{Y_2(o)}{Z(o)} = \frac{bK_1\left[q + \frac{2mq}{2} - (1+m)q\right]}{-\frac{L_o b}{T_s}\left\{\frac{T_s}{T_o}q + m\frac{T_s}{T_o}q\right\}} = \frac{K_1(1+m-1-m)}{-\frac{L_o}{T_s}\frac{T_s}{T_o}(1+m)} = 0 \tag{77}$$

which means that the sustained value of flux density due to the eddy currents is zero.

For eq 58, $\frac{Y_1(o)}{Z(o)}$ can be determined in a similar manner.

$$\frac{Y_1(o)}{Z(o)} = \frac{-b\left(q+\frac{2mq}{2}\right)}{-\frac{L_o b}{T_s}\left(\frac{T_s}{T_o} + 2\frac{m}{T_o}\frac{q}{2}\right)} = \frac{1}{R} \tag{78}$$

This result checks Ohm's law in that the steady state value of the exciting current must be equal to the applied voltage divided by the resistance.

Similarly $\frac{Y\phi(o)}{Z(o)}$ for eq 59, becomes

$$\frac{Y\phi(o)}{Z(o)} = \frac{-\frac{2bL_o}{N}(1+m)\frac{q}{2}}{-\frac{L_o bq}{T_o}(1+m)} = \frac{T_o}{N} = \frac{L_o}{RN} \tag{79}$$

Therefore on substituting eqs 73 to 76 in eqs 57 to 59 the solutions for B_2, i, and ϕ_t, become as shown in eqs 80 to 85, inclusive.

The foregoing equations use the quantity m as a parameter; this quantity is the ratio of the equivalent air gaps, a/b. It is more convenient to express the relation between these equivalent gaps by introducing a term which expresses the fraction of the total magnetomotive force consumed by the solid iron part under steady state conditions. This fraction will be designated by n. The relations between m and n are then

$$m = \frac{1-n}{n} \tag{86}$$

$$n = \frac{1}{1+m} \tag{87}$$

Equations 80 to 85

$$B_2 = VbK_1\sum_1^\infty\left[\frac{qJ_o(q) + 2mJ_1(q) - (1+m)qJ_o\left(\frac{2qr}{d}\right)}{-\frac{qL_o b}{2T_s}\left\{\left[\frac{T_s}{T_o}(1+2m) - 2(1+m+m\sigma)q^2 - 3\sigma q^2\right]J_o(q) - \left[\frac{T_s}{T_o}\left(q+\frac{2m}{q}\right) - \sigma q^3 + 2(1+m+m\sigma)q\right]J_1(q)\right\}}\right]_{q=q_\nu}\epsilon^{-\frac{q_\nu^2}{T_s}} \tag{80}$$

$$i = \frac{V}{R} + V\sum_1^\infty\left[\frac{-b[qJ_o(q) + 2mJ_1(q)]}{-\frac{qL_o b}{2T_s}\left\{\left[\frac{T_s}{T_o}(1+2m) - 2(1+m+m\sigma)q^2 - 3\sigma q^2\right]J_o(q) - \left[\frac{T_s}{T_o}\left(q+\frac{2m}{q}\right) - \sigma q^3 + 2(1+m+m\sigma)q\right]J_1(q)\right\}}\right]_{q=q_\nu}\epsilon^{-\frac{q_\nu^2}{T_s}t} \tag{81}$$

$$\phi_t = \frac{VL_o}{RN} + V\sum_1^\infty\left[\frac{-\frac{2\times 10^8 bL_o(1+m)}{N}J_1(q)}{-\frac{qL_o b}{2T_s}\left\{\left[\frac{T_s}{T_o}(1+2m) - 2(1+m+m\sigma)q^2 - 3\sigma q^2\right]J_o(q) - \left[\frac{T_s}{T_o}\left(q+\frac{2m}{q}\right) - \sigma q^3 + 2(1+m+m\sigma)q\right]J_1(q)\right\}}\right]_{q=q_\nu}\epsilon^{-\frac{q_\nu^2}{T_s}t} \tag{82}$$

Equations 80, 81, and 82 may be simplified as follows:

$$B_2 = -\frac{V}{R}\frac{T_s}{T_o}2K_1\sum_1^\infty\left[\frac{2m + q\frac{J_o(q)}{J_1(q)} - (1+m)q\frac{J_o\left(\frac{2qr}{d}\right)}{J_1(q)}}{q\left\{\left[\frac{T_s}{T_o}(1+2m) - q^2(2[1+m+m\sigma]+3\sigma)\right]\frac{J_o(q)}{J_1(q)} - \frac{T_s}{T_o}\left(q-\frac{2m}{q}\right) + \sigma q^3 - 2q(1+m+m\sigma)\right\}}\right]_{q=q_\nu}\epsilon^{-\left(\frac{q_\nu^2 T_o}{T_s}\right)\frac{t}{T_o}} \tag{83}$$

$$i = \frac{V}{R}\left\{1 + 2\frac{T_s}{T_o}\sum_1^\infty\left[\frac{2m + q\frac{J_o(q)}{J_1(q)}}{q\left\{\left[\frac{T_s}{T_o}(1+2m) - q^2(2[1+m+m\sigma]+3\sigma)\right]\frac{J_o(q)}{J_1(q)} - \frac{T_s}{T_o}\left(q-\frac{2m}{q}\right) + \sigma q^3 - 2q(1+m+m\sigma)\right\}}\right]_{q=q_\nu}\epsilon^{-\left(\frac{q_\nu^2 T_o}{T_s}\right)\frac{t}{T_o}}\right\} \tag{84}$$

$$\phi_t = \frac{VT_o}{N}\left\{1 + 4\frac{T_s}{T_o}\sum_1^\infty\left[\frac{1+m}{q\left\{\left[\frac{T_s}{T_o}(1+2m) - q^2(2[1+m+m\sigma]+3\sigma)\right]\frac{J_o(q)}{J_1(q)} - \frac{T_s}{T_o}\left(q-\frac{2m}{q}\right) + \sigma q^3 - 2q(1+m+m\sigma)\right\}}\right]_{q=q_\nu}\epsilon^{-\left(\frac{q_\nu^2 T_o}{T_s}\right)\frac{t}{T_o}}\right\} \tag{85}$$

Theory of Primary Networks—Part II

This paper, Part II of a group on theory of primary electric power distribution networks, deals with short-circuit and relay problems. Data showing the distribution of fault currents for both 3-phase and ground faults is presented, and a rational method of relaying based upon that data is discussed and analyzed.

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IN ORDER that primary electric power distribution networks may be designed to give optimum service reliability, and in order that circuit breakers having adequate interrupting capacities may be provided, the maximum possible fault currents that can exist must be known. This paper, Part II of a group on theory of primary networks (for Part I, which dealt primarily with voltage regulation and load distribution problems, see ELECTRICAL ENGINEERING, v. 53, Feb. 1934, p. 310–18) presents results of calculating board studies showing maximum possible faults on typical primary networks having a variety of characteristics, with tie line impedance, load density, and kilovoltampere capacity of the networks as parameters. Data showing the distribution of fault current for both 3-phase and ground faults is given.

Upon the basis of the fault data presented, methods of relaying that are best fitted to give reliable operation and service continuity are described and analyzed. An example is given demonstrating the method of calculating relay settings for a typical network. Special network operating conditions also are discussed briefly; however, no operating difficulty has been found that cannot be remedied satisfactorily in a fairly simple and inexpensive manner.

Magnitude of Faults on Primary Networks

Maximum Possible Faults

It is of considerable importance to know the magnitude of faults in primary networks having various characteristics in order that the networks may be designed to give optimum service reliability, and in order that circuit breakers having adequate interrupting capacities may be provided. A section of a typical primary network is shown in Fig. 1. The maximum possible fault that can occur on the 4-kv network will be located either on the unit substation bus or immediately outside the feeder circuit breaker.

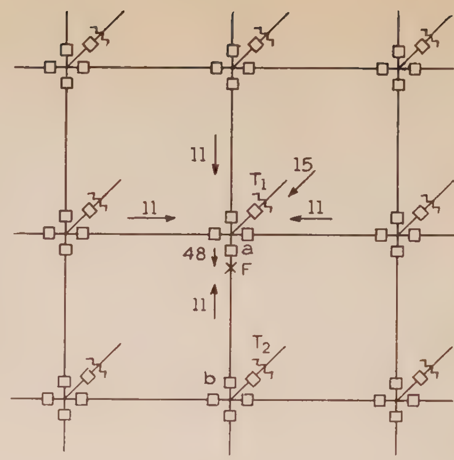

Fig. 1. Section of a typical primary network

This figure shows the distribution of fault currents for the maximum possible fault that can occur on a large network. Network ties having an impedance of 6 per cent and transformers having a reactance of 6 per cent (1500-kva base) are assumed. Currents are in "times-normal" current of the network transformer rating

Consider such a fault at point F, for example, on the network unit fed by transformer T_1. Since the maximum fault exists when the impedances of the generating system and transmission lines feeding the network are minimum, such a condition will be assumed (actually about 0.4 per cent in this case). It will be assumed further that the network is very large (i. e., it is infinite so far as faults at any internal point are concerned), that the network ties are overhead lines having impedances of 6 per cent, and that the transformer reactances are 6 per cent. (All per cent impedances are on a 1,500-kva base, the rating of the unit. The tie impedance of 6 per cent in this case corresponds to a load density of about 1,400 kva per square mile.) With these conditions the maximum possible 3-phase fault at point F will be 59 times normal (normal being 1,500 kva). The maximum current through a feeder breaker for this particular fault is 48 times normal or 72,000 kva. If transformer T_1 were out of service, a likely condition, the fault current through breaker A would be reduced to 33 times normal.

A fault at point F results in breaker A opening first, after which the current through breaker B increases from 11 times normal to 12.4 times normal. Of this current, approximately 23 per cent will come from each of the other 3 network ties and 31 per cent will flow from transformer T_2. If transformer T_2 should be out of service, the current fed to the fault through breaker B would be less by the 31 per cent which T_2 otherwise would carry. (This condition exists only in networks having 5 or more network units; the network considered here is assumed to be infinite.)

In the foregoing example, the maximum fault in a network having 6 per cent impedance mains was found to be 59 times normal. The curve in Fig. 2 gives similar values of maximum faults plotted against network tie impedance. A curve showing the distribution of this fault into each of the adjacent ties also is given. The curves in Fig. 2, as in the previous example, presume a very large network,

Full text of a paper recommended for publication by the A.I.E.E. committee on transmission and distribution. Manuscript submitted Oct. 23, 1933; released for publication Feb. 5, 1934. *Not published in pamphlet form.*

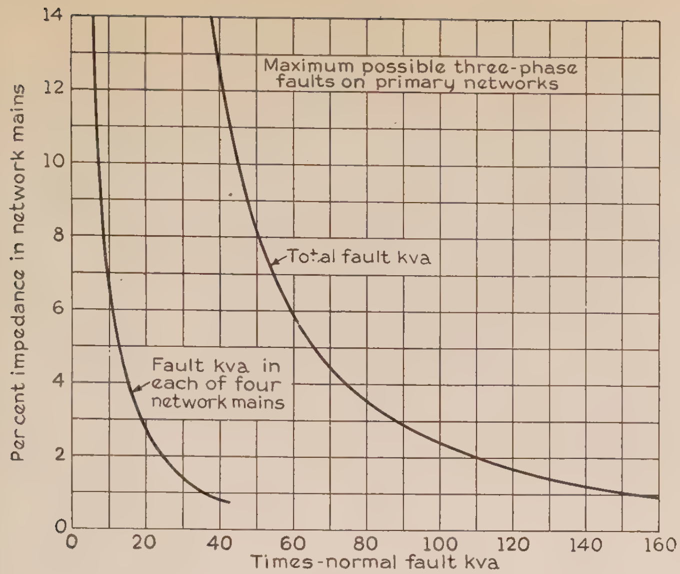

Fig. 2. Maximum possible faults on primary networks

These curves show the maximum possible 3-phase fault that can occur on a very large primary network, as a function of tie line impedance. Currents are in "times-normal" rating of the network transformer, and the impedance base is the kilovoltampere rating of the network transformer

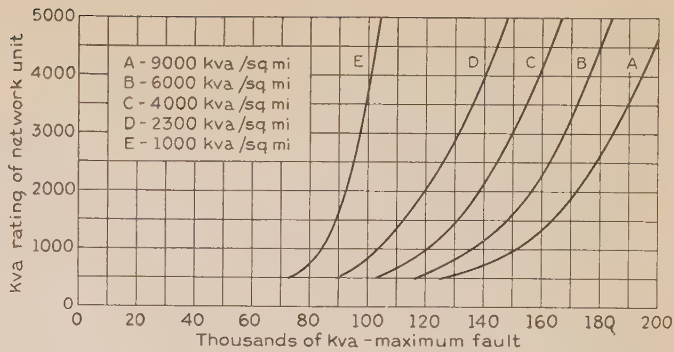

Fig. 3. Variation of fault kilovoltamperes with load density and network unit rating

These curves show the maximum possible 3-phase faults that can occur on a very large primary network, as a function of load density and kilovoltampere rating of the network unit. Network transformers having 6-per cent reactance are assumed in each case

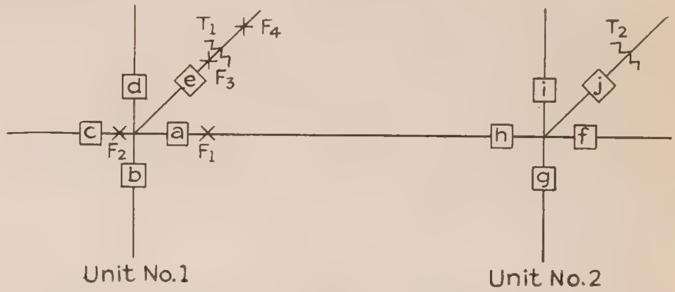

Fig. 4. Equivalent impedance diagram of the primary network unit and connected system

For the purpose of studying fault conditions in the average primary network having from 5 to 10 units, the above impedance elements are sufficient. Refer to Table I

a low impedance transmission system, 6 per cent reactance transformers, etc.

The size of network unit that has been found most economical for most applications is 1,500 kva; and unless otherwise stated, this is the rating of unit considered throughout this paper. However, it is of interest to note how the maximum possible fault currents vary with the size of network unit. For a given load density, the larger the unit, the farther apart they are and the greater the impedance of the ties. The greater tie impedance tends to reduce fault currents, but the increased transformer capacity of the larger units tends to increase fault currents. For a given size of unit an increase in load density results in shorter ties, more units, and increased magnitude of faults. These relations are shown quantitatively in the curves of Fig. 3.

From economic considerations, primary networks in most cases will not be applied to load densities greater than 10,000 kva per square mile. It appears, therefore, from the curves of Fig. 3, that a primary network having 1,500-kva units and overhead ties (the curves of Figs. 2 and 3 are based upon overhead ties) is subject to a maximum 3-phase fault of about 180,000 kva. If cable ties are used this maximum will approach 225,000 kva.

Usually the most severe fault on a system is a 3-phase fault, but in some cases the most severe network fault is a ground fault. A ground fault may be 5 or 10 per cent greater than a 3-phase fault. However, 3-phase faults are the best standards for comparative purposes since ground faults vary between wide limits depending on system conditions.

In some cases, the transmission lines feeding a network receive their power not directly from a generating station, but rather from a long transmission line with high-reactance transformer banks at either end. A system of this type materially reduces the maximum possible faults on a network. The maximum fault on a network fed in this manner may be approximated closely by considering the transmission system as a lumped impedance and applying the following simple formula

$$I = \frac{100\,I'}{100 + ZI'}$$

where Z is the lumped impedance of the transmission system (1,500-kva base), I' is the apparent maximum fault current as read from the curves of Fig. 2 or 3, and I is the true maximum fault current.

The preceding data has been found extremely useful in determining circuit breaker interrupting duties on a rational and economic basis. In networks having underground cable ties, 250,000-kva breakers have been adopted; networks having overhead ties have been equipped with breakers having ratings of 100,000 and 150,000 kva. In one case, a network having underground cable ties, but a high impedance transmission system, was equipped with 100,000-kva breakers; however, in this case a 50,000-kva breaker would have been adequate for load densities up to 5,000 kva per square mile.

Faults in Typical Networks

The foregoing material has considered the maximum possible faults on a primary network. In addition to this information it was necessary to know the actual faults, both 3-phase and ground, that are likely to be encountered in a typical network

of relatively small size. This information is particularly useful, not only to determine relay settings to give optimum service reliability, but also to establish the most satisfactory method of relaying.

For the purpose of studying faults on a typical network, a single network transformer and lumped impedances representing the network as viewed from the low voltage side of the transformer, and the transmission system as viewed from the high voltage side of the transformer, will be adequate. The single-line diagram of such an arrangement is shown in Fig. 4. The impedances H, L, and T represent the equivalent "Y" of the network transformer; impedance S represents the transmission system and impedance N represents the network. The faults in which we are interested are F_H on the high voltage side of the transformer and F_L on the low voltage side.

Constants that are typical of several networks having from 5 to 10 units which the author has analyzed are shown in Figs. 5 and 6. The positive, negative, and zero phase impedance diagrams are shown for 2 types of network transformers in common use: the Y-Y transformer with Δ tertiary (Fig. 5); and the Y-zigzag transformer with Δ tertiary (Fig. 6). This latter transformer connection is used where it is desirable to parallel the network with an existing Δ-Y substation.

For the 2 cases shown in Figs. 5 and 6, 3-phase and ground faults at points F_H and F_L have been calculated. The results of these calculations are given in Table I. It is interesting to note in this case that ground faults on the low-voltage side are somewhat greater than are the 3-phase faults. The maximum faults possible in this network are seen to be about 50 times normal or 75,000 kva. The difference in distribution of ground fault currents between the Y-Y and the Y-zigzag transformers should be noted. The data in Table I will be considered more fully later in the paper in connection with relay settings.

Relaying the Primary Network

As in any well designed distribution system, the network relay equipment must be adequate to remove faulty sections as quickly as possible and to insure that all other sections shall not be disturbed. Furthermore, it must provide a means of restoring service automatically to the extent that such restoration is feasible. The network relay equipment must be suitable for fault conditions not only on a particular network but also for potential fault conditions that may exist at any time during the growth of the network. It must be sufficiently flexible to be readily adaptable to any particular form the network may take in its future development.

The several fault conditions to be considered are shown in Fig. 7; they may be summarized as follows:

1. Faults on the 4-kv network tie, as at F_1 (or faults on any lateral extension from the tie).
2. Faults on the network unit bus, as at F_2.
3. Faults on the low voltage side of the transformer, as at F_3.
4. Transmission line faults, as at F_4.
5. Internal transformer faults.

Because of the general limitations of network installations, relays for this service must be relatively inexpensive, must occupy a minimum of space, and must require infrequent inspection.

Recommended Network Relays

Before analyzing the various network fault conditions upon which the choice of suitable relays has been based, it seems pertinent to describe briefly the general relay scheme that has been adopted in practice and found to be satisfactory.

All factors being considered, the inverse-time overcurrent relay has been found most desirable for primary tie line and bus protection, i. e., for faults F_1 and F_2 shown in Fig. 7. Common practice is to

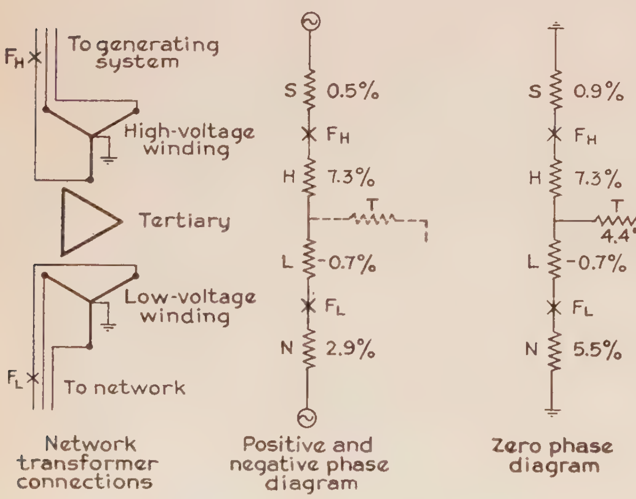

Fig. 5. Impedance constants for Y-Y network transformer and connected system

The above positive, negative, and zero phase reactances may be used in studying fault conditions in a typical primary network having from 5 to 10 units, each having a Y-Y transformer with grounded neutrals. Refer to Table I

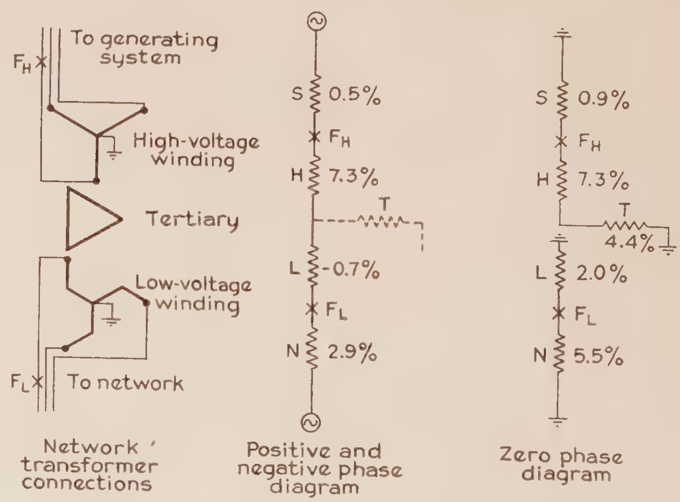

Fig. 6. Impedance constants for Y-zigzag network transformer and connected system

The above positive, negative and zero phase reactances may be used in studying fault conditions in a typical primary network having from 5 to 10 units, each having a Y-zigzag transformer with grounded neutrals. Refer to Table I

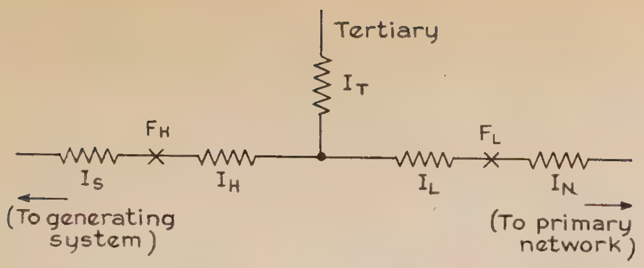

Fig. 7. Elements of a primary network and typical faults

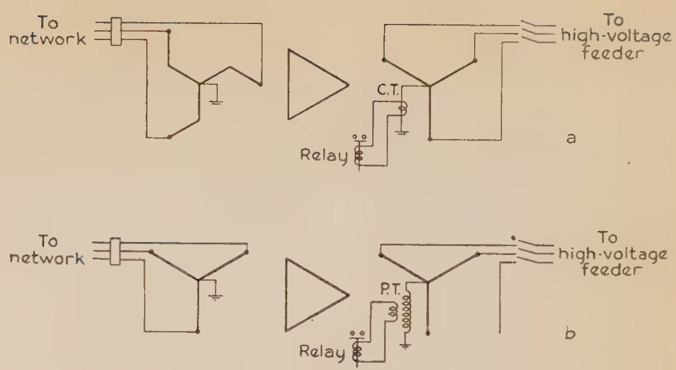

Fig. 8. Selective relaying of high voltage ground faults

a. This scheme is applicable only to transformers having zigzag windings

b. This is the conventional method of obtaining selective ground protection

provide a set of inverse-time overcurrent relays to trip each feeder breaker (i. e., breakers *a*, *b*, *c*, or *d* in unit No. 1) in the event of feeder faults. Another set of inverse-time overcurrent relays excited by the transformer current is provided to trip the transformer breaker *e* and all feeder breakers in case of a bus fault, and also to trip all breakers in the event of a failure of feeder protective equipment.

In addition to the time overcurrent relays for feeder faults, instantaneous relays are provided the tripping contacts of which are in parallel with those of the time overcurrent relays. These instantaneous elements are set with a relatively high pick-up and are intended to clear all faults on the network tie line having a magnitude greater than the maximum current that any fault external to the tie lines in question may impose upon it. Since the time overcurrent relays have an extremely inverse characteristic, the combination with the instantaneous element insures unusually rapid isolation of all feeder faults.

In at least one installation bus differential protection has been provided in addition to the overcurrent protection for bus faults. The addition of differential protection is an added factor of safety insuring the rapid removal of bus faults, but it is not considered necessary for reliable network operation.

Transformer and transmission line faults, i. e., all faults such as F_3 and F_4 outside of transformer breaker *e*, are isolated by means of a reverse power relay in conjunction with an overcurrent relay, the tripping contacts of the 2 relays being in series. With this arrangement a reverse power flow of sufficient magnitude through the transformer breaker *e* will trip breaker *e* to isolate any transformer or transmission line fault. In some cases it may be desirable to trip transformer breaker *e* instantaneously for certain faults above a certain magnitude. For this purpose an instantaneous element with adjustable pick-up may be connected to operate in parallel with the time overcurrent relay in the same manner as outlined for the tie line relays.

It should be noted here that the foregoing relay devices are intended to function for ground faults as well as phase faults. If both sides of the network transformer are grounded, which is usually the case, ground fault currents always will be of sufficient magnitude to operate the overcurrent relays. This fact is borne out by actual experience on networks in operation, and also by several network short-circuit studies which the author has made. In some networks it may not be permissible to ground the neutral of the high voltage winding of the transformer. In such cases a potential transformer may be inserted between the neutral and ground to provide excitation for a voltage relay as shown in Fig. 8b. The potential transformer, normally unexcited, will be impressed with "leg" voltage in the event of a ground fault.

If the network transformer happens to have a zigzag winding, which some of them do have, selective ground fault protection may be provided in a very simple manner. In a transformer of this type, ground faults on the high voltage side cannot initiate zero-phase currents in the low voltage winding; and, similarly, ground faults on the low voltage side cannot initiate zero-phase currents in the high voltage winding. Because of this characteristic of transformers having zigzag windings, very selective and sensitive ground fault protection for transmission line faults may be obtained by simply inserting an overcurrent relay in the neutral of the high voltage winding as shown in Fig. 8a. This relay may be instantaneous and may be given an extremely low pick-up. A similar relay might be inserted in the neutral of the low voltage winding for selective relaying of 4-kv ground faults, but this refinement never is necessary.

In order to demonstrate the adequacy of the relay methods outlined, it seems pertinent to consider the details of relaying an actual network. For this purpose the data applying to a typical network and tabulated in Table I will be used. The analysis for both high voltage and low voltage faults is given in the following paragraphs.

Isolating Faults on Network Tie Lines

From the standpoint of selectivity and speed of operation, the tie line faults (or primary feeder faults as they sometimes are called) are of considerable importance and perhaps require more study than all other network faults. Refer again to the network elements shown in Fig. 7. Reliable fault protection requires that a feeder fault such as F_1 must open breakers *a* and *h* as quickly as possible and must fail to open all other breakers. The cycle of operation for fault F_1 is as follows: Circuit breaker *a* opens first, probably instantaneously; this allows the

current to rise in breaker h which is tripped either instantaneously or after a slight time delay. It is desirable that the instantaneous elements of the feeder relays be set with low enough pick-up to permit instantaneous tripping for most feeder faults. Of course the minimum faults that occur at the extremities of the laterals connected to the network ties will not operate the instantaneous relays, but must rely on the time overcurrent relays.

The instantaneous elements are set to pick up on a value of current substantially greater (usually 10 per cent greater) than the maximum possible current that can be drawn through the breaker as a result of any external fault under any probable operating condition. (Note that one probable operating condition is that of a transformer at either end of the faulty section being out of service.) It will be found that this criterion permits practically all faults on the tie line itself to be cleared instantaneously.

For any fault less than the pick-up setting of the instantaneous element, the inverse-time overcurrent element must operate. The time overcurrent relay should have a minimum pick-up corresponding to the minimum fault that can occur on any long lateral tied to the feeder. The time lever setting of this relay must be such that the time required for it to close its contacts when its feeder is faulted must always be at least 0.4 to 0.5 sec less than the corresponding time for any relay on an adjacent feeder under the same fault condition. Since the minimum time differentials occur for the maximum faults, and since the maximum fault for which the time overcurrent element is required to operate is the pick-up current of the instantaneous element, a good conservative criterion for setting the time lever of the time overcurrent relay is that the tripping time for a fault corresponding to the pick-up of the instantaneous element should be at least 0.5 sec faster than the tripping time for a fault of half this value. It is a rare condition in a well designed network for a sound feeder to carry more than 50 per cent of the current in an adjacent faulty feeder.

With the foregoing criteria as a basis, the fault data given in Table I, which is representative of a typical network, may be used in determining typical relay settings. The network elements of Fig. 7 may be used again for reference. Table II has been prepared to show the distribution of currents in the various breakers of Fig. 7 for fault F_1 under several probable operating conditions. The data here is taken directly from Table I, a Y-Y transformer being assumed.

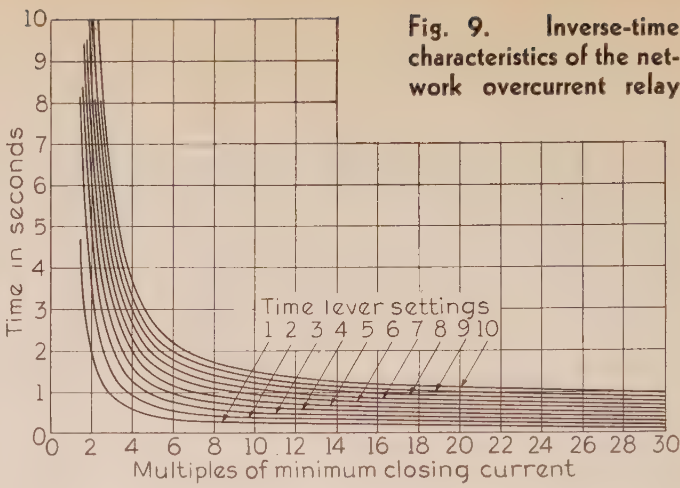

Fig. 9. Inverse-time characteristics of the network overcurrent relay

Fault F_1 draws 39.9 times normal current through breaker a and 8.6 times normal through breaker h (assuming a 3-phase fault with T_1 and T_2 in service); after breaker a opens the current in h increases to 13.4 times normal. These currents are somewhat different for ground faults and for the condition of T_1 or T_2 being out of service. The maximum current that can flow in a sound feeder owing to any external fault condition is 8.7 times normal; therefore, on the basis of the foregoing criterion, the instantaneous elements should be set to pick up on 1.10×8.7 or 9.6 times normal current. With this setting all faults on the feeder itself will be cleared instantaneously except a fault at F_1 with T_2 out of service.

All faults of less than 9.6 times normal must be cleared by means of the time overcurrent relay. It will be assumed here that the minimum possible fault is 4 times normal. The pick-up of the time overcurrent relay should be set somewhat less than this value, say 3 times normal. Refer now to Fig. 9 which shows the very inverse time characteristic of the recommended network relay. Note that a current of 9.6 times normal (which is 3.2 times minimum pick-up) will close the tripping contacts in 0.9 sec (No. 1 time lever setting) whereas half this current requires 3 sec for tripping. Since the differential is much greater than the required 0.5 sec, No. 1 time lever setting may be used with safety.

Isolating Bus Faults

As pointed out previously in this paper, bus faults are isolated by means of an inverse-time overcurrent relay that has exactly the same time characteristics as the feeder relays (but no instantaneous

Table I—Maximum Fault Currents in Average Small-Sized Primary Networks

Type of Faults	Transformer Connection	High-Voltage Faults—FH						Low-Voltage Faults—FL					
		I_f	I_s	I_h	I_l	I_n	I_t	I_f	I_s	I_h	I_l	I_n	I_t
3-Phase	Y-Y	210	199.5	10.5	10.5	10.5	0	48.5	14.1	14.1	14.1	34.4	0
	Y-zigzag	210	199.5	10.5	10.5	10.5	0	48.5	14.1	14.1	14.1	34.4	0
Ground	Y-Y	169	158.7	10.5	7.95	7.95	2.52	52.9	14.7	14.7	22.9	30.0	8.24
	Y-zigzag	168	158.4	9.6	5.6	5.6	4.0	53.7	10.4	10.4	23.5	30.2	0

This data applies to an average small-sized network (4 to 10 units) and an average transmission system. All fault currents are given in "times-normal" values (normal current corresponds to 1,500 3-phase kva in this case). For the following symbols, refer to Fig. 4:

I_f = fault current
I_s = transmission line current
I_h = transformer current on high voltage side
I_l = transformer current on low voltage side
I_n = net work current
I_t = transformer tertiary current

element is provided) and that operates to trip the transformer breaker when the transformer current exceeds a predetermined value. In addition to bus protection this relay provides "back-up" for the feeder relays.

Since the bus relay serves as a "back-up" device, it should have the same minimum pick-up setting as the feeder relays. Continuing the foregoing example in reference to Fig. 7 and the fault data in Tables I and II, then, the minimum pick-up of the transformer relay should be set at 3 times normal current.

Inasmuch as the bus relay will operate only on rare occasions, its speed may be sacrificed to a certain degree to insure that false operation will not result in the event of a heavy feeder fault. Furthermore, the bus relay should be set on the basis that the instantaneous elements of the feeder relays may fail to function. It will be stipulated therefore that the transformer relay shall be at least 0.6 sec slower than any feeder relay for the worst possible feeder fault. Refer now to Table II and note that the worst feeder fault is a ground fault that imposes a current on breaker *a* of 45.4 times normal and a current on breaker *e* of 22.9 times normal. For these values of fault currents it may be noted from Fig. 9 that the transformer relay must have a time lever setting of 5 in order to obtain a time differential of 0.6 sec.

Transformer and Transmission Line Faults

As already noted the transformer or transmission line faults are isolated by virtue of the operation of a polyphase power-directional relay and an overcurrent relay to trip the transformer breaker. The tripping contacts of the 2 relays are in series. The overcurrent relay should be set to pick up on all fault currents likely to flow in the transformer or on the high voltage feeder. However, it should be set high enough to insure that false operation will not result from circulating currents.

Refer again to Fig. 7. For a fault such as F_4 the current in transformer breaker *e* may be almost zero before the station breaker opens. After the station breaker opens however, this current will rise to a value varying from 8 to 14 times normal depending on various circuit conditions. The pick-up setting selected for the overcurrent relay will be determined largely by the nature of the transmission line. For the typical network considered in Table I, however, a pick-up setting of 4 times normal would appear to be entirely adequate to clear all high voltage faults. The time lever setting of this relay should be very fast to insure that the feeder breakers shall not be tripped for high voltage faults. An instantaneous element is recommended to be used in parallel with the overcurrent relay to clear heavy faults, such as those occurring at point F_3, as rapidly as possible. Such a relay might be set to pick up at currents of 8 times normal.

Restoration of Service

Closely associated with the protective devices of the primary network equipment are the reclosing features. The recommended reclosing characteristics will be described briefly. Each feeder breaker is equipped with a reclosing and timing relay that may be adjusted to provide 1, 2, or 3 reclosures at predetermined intervals. Automatic reclosure of a feeder breaker is effected only after automatic tripping due to a feeder fault. A circuit interruption for any other cause requires manual resetting of the breaker.

Automatic reclosure of the transformer breaker is effected by means of a voltage reclosing relay. This relay operates to reclose the transformer breaker only after it has been tripped by the action of the reverse power relay and provided 3-phase voltage of the correct phase rotation exists on the transmission feeder.

When the transformer overcurrent relay operates from any cause whatever, all 5 network breakers are tripped and locked out and must be reset manually.

Special Operating Conditions

Occasionally some one presents a special operating condition that appears to offer some difficulty to the satisfactory relaying of a network. For example, the question of relaying an isolated transmission feeder or of relaying high voltage ground faults of extremely low magnitude frequently is brought up. Again, the question of relaying transmission feeders when rapid breaker reclosures are required is debated. The author has studied these and several other special operating problems, and in no case has he been able to find any difficulty that cannot be remedied satisfactorily in a fairly simple and inexpensive manner.

Table II—Distribution of Fault Currents in the Various Breakers Shown in Fig. 7, for a Fault at F_1

Types of Faults	Breakers	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*
3-Phase		39.9	8.6	8.6	8.6	14.1	1.9	1.9	8.6	1.9	3.0
	a open	0					2.9	2.9	13.4	2.9	4.7
	e open	26.1	8.7	8.7	8.7	0	1.9	1.9	8.7	1.9	3.1
	e and *a* open	0				0	2.8	2.8	13.1	2.8	4.7
	j open	39.9	8.6	8.6	8.6	14.1	2.0	2.0	6.0	2.0	0
	j and *a* open	0					3.0	3.0	9.0	3.0	0
Ground		45.4	7.5	7.5	7.5	22.9	1.2	1.2	7.5	1.2	3.8
	a open	0					2.3	2.3	13.9	2.3	7.0
	e open	23.4	7.8	7.8	7.8		1.3	1.3	7.8	1.3	3.9
	e and *a* open	0				0	2.2	2.2	13.6	2.2	7.0
	j open	45.4	7.5	7.5	7.5	22.9	1.3	1.3	3.9	1.3	0
	a and *j* open	0					2.4	2.4	7.2	2.4	0

Network constants and fault conditions corresponding to the fault data on a typical network as shown in Table I were assumed in preparing this table (this case being for a Y-Y transformer). The above currents are given in "times-normal" values for various operating conditions.

The Theory of Incremental Rates and Their Practical Application to Load Division—Part I

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The calculation of the most economical division of load between generating units and power plants is of considerable importance on large inter-connected systems. The most complete analysis of the subject of load division published to date is contained in the present paper, which shows that the method of incremental rates gives the division of load which is the most economical. Both the basic theory and the practical application of the method are contained in this paper. An outline is given in the accompanying table of contents.

Table of Contents—Part I

Part I of a paper recommended for publication by the A.I.E.E. committee on power generation. Manuscript submitted July 11, 1933; released for publication Sept. 7, 1933. *Not published in pamphlet form.*

Introduction

THE INCREASING number of interconnections between large generating stations in recent years has necessitated the discarding of methods of calculating load division which do not result in the most economical generation, and the acceptance of the incremental rate method instead. Although much has been written on the subject of load division, a review of the literature shows that there is a need for a comprehensive discussion on the theory and nature of incremental rates and their practical application. It is hoped that this paper will supply that need.

The failure to understand fundamentals often results in the incorrect application of incremental rates. Two specific cases will suffice to illustrate. *First,* the failure to recognize the conditions under which equal loading of identical turbine-generators will not result in maximum combined economy. *Second,* the failure to realize that for machines with mathematically discontinuous performance curves, incremental rates alone may not be sufficient to determine the proper load division.

In addition to the theoretical aspects of the subject, there is the practical side to be considered. The calculation of the performance curves which constitute the basis of incremental loading, may be too laborious or even impossible for a complete, academically correct solution. Approximate methods which must therefore be resorted to, are suggested in this paper and should be helpful to

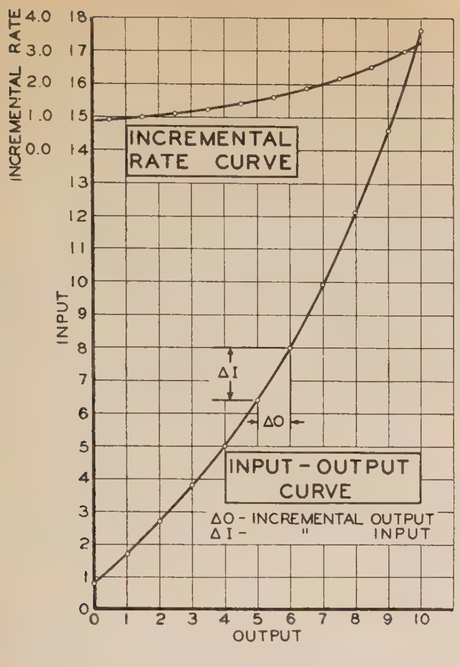


Fig. 1 Derivation of incremental rate curve from input-output curve

those engaged in such calculations. The factors which require consideration and methods of correlating them are discussed in detail.

Although the wide scope of the subject has made it necessary to limit the discussion of some phases, an effort has nevertheless been made to present a complete picture of the problem by always indicating at least the principles involved.

Theoretical Background

When 2 or more machines or groups of machines are operated in parallel, the combined efficiency of operation is affected by the division of the total output among the machines. It will subsequently be shown that the maximum combined efficiency is usually obtained when the machines are operated at outputs corresponding to equal incremental rates. This establishes a definite relation between the total output and the outputs of the individual machines. In order to determine this relation, it is necessary to know, for each machine, the relation between the output and the corresponding input. This is defined by the conventional efficiency curve or by the more fundamental input-output curve. For expediency in computing incremental rates, the use of the latter is preferable.

Incremental Rates

The incremental rate at any given output is the slope of the input-output curve at the point corresponding to that output. The slope of the input-output curve, and hence the incremental rate, measures the *rate of increase* of the input and should not be confused with the absolute value of the input.

The incremental rate may be derived by one of the following methods:

1. When the input-output curve can be expressed by an algebraic equation, the incremental rate can be derived by differentiation, since it is the first derivative of the equation for the input-output curve.

2. A tangent may be drawn to the input-output curve at the point corresponding to the output. The slope of the tangent is the incremental rate at the given output.

3. In actual practice the slope is usually determined graphically by an approximate method. The input-output curve is drawn, a series of output values are chosen and the corresponding input values are read. The differences between successive values of the output are usually made constant and are made small enough to insure that the characteristic of the incremental rate is accurately determined. The latter is merely the ratio of the input difference to the output difference, and is assumed to be a function of the mid-point. The output and input differences are termed respectively, incremental output and incremental input. This method is illustrated in Fig. 1 and Table I.

The physical significance of the incremental rate can best be illustrated by the following example. Consider 2 boilers supplying a common load and operating at equal outputs with incremental rates and efficiencies as shown below.

	Boiler A	Boiler B
Boiler output, million Btu per hour	10	10
Incremental rate	1.42	1.33
Boiler efficiency, per cent	80	70

If it were necessary to increase the total output by one million Btu per hour, then the additional output should be supplied by boiler *B*, notwithstanding the fact that boiler *A* is more efficient. The criterion is not the relative boiler efficiencies but the relative efficiencies of generating the *additional* or *incremental outputs*. Thus the incremental inputs for the additional output would be 1.42 and 1.33 million Btu per hour, respectively, for boilers *A* and *B*. The efficiency of generating the additional output would be $\frac{1 \times 100}{1.42} = 70.42$ per cent for boiler *A* and $\frac{1 \times 100}{1.33} = 75.19$ per cent for boiler *B*.

Thus it is the *efficiencies of generation* of the *incremental outputs* or the *incremental efficiencies* which should determine the division of load be-

Table I—Calculation of Incremental Rate Curve From Input-Output Curve

Output	Incremental Output	Input	Incremental Input	Incremental Rate	Output Against Which Incremental Rate Is Plotted
0		0.8			
	1.0		0.9	0.9	0.5
1		1.7			
	1.0		1.0	1.0	1.5
2		2.7			
	1.0		1.1	1.1	2.5
3		3.8			
	1.0		1.2	1.2	3.5
4		5.0			
	1.0		1.4	1.4	4.5
5		6.4			
	1.0		1.6	1.6	5.5
6		8.0			
	1.0		1.9	1.9	6.5
7		9.9			
	1.0		2.2	2.2	7.5
8		12.1			
	1.0		2.5	2.5	8.5
9		14.6			
	1.0		3.0	3.0	9.5
10		17.6			

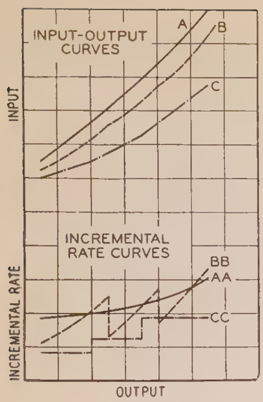
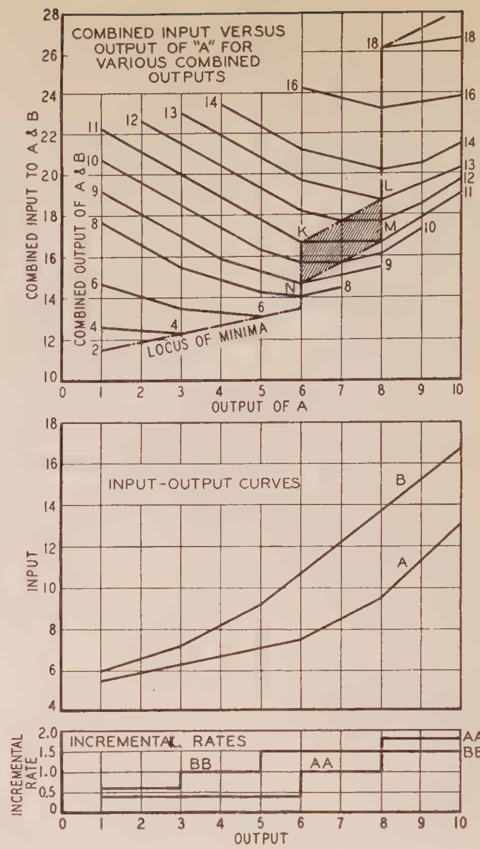


Fig. 2. Types of input-output and corresponding incremental rate curves

Fig. 3. Load division between 2 units having discontinuous incremental rates but no decreasing values



tween machines, and not their respective absolute efficiencies.

Since the incremental rate was defined as the ratio of incremental input to incremental output, the incremental efficiency expressed as a decimal becomes the reciprocal of the incremental rate.

Conditions for Maximum Efficiency

In Appendix A is a mathematical analysis establishing the conditions for maximum overall efficiency when 2 units of different characteristics are operating in parallel to supply a common load.

The minimum input (subject to the conditions laid down in the subsequent section) for the given combined output is obtained when the incremental rates of the 2 units are equal. Furthermore, there is only one pair of loads for any given output at which the incremental rates will be equal.

Many input-output curves are found to be continuous, but to have discontinuous incremental rate curves. If it happens that, as in the case of curve C Fig. 2, the slope or incremental rate of the curve changes suddenly at certain points, yet *never decreases as the output increases*, the incremental rate may be used as simply as if it were everywhere continuous. It is only necessary to consider that *at the point of discontinuity* (where the incremental rate has a step-like increase), the incremental rate takes all the values between the lower and upper limits. There will be only one pair of loads at any given total output for which the input will be a minimum, excepting the case where units have ranges in which the incremental rates are equal as well as constant. For such a condition there will be many combinations for any total output within the given range, for which the input will be constant. This will be the lowest obtainable combined input.

An illustration of the effect of varying load division on the combined input of 2 machines is shown in Fig. 3. Machines A and B have continuous input-output curves consisting of portions of intersecting straight lines. Their incremental rate curves, AA and BB are discontinuous and consist of successive horizontal straight lines; the incremental rates have ranges in which they are equal and constant. The curve net shows, for various constant values of the combined output, the combined input plotted as a function of the load on machine A. The locus of the minimum points is shown. It is an inclined or vertical straight line everywhere except for combined loads between the values of 9 and 13, for which it becomes a plane area included in the parallelogram K-L-M-N. For any combined load in that range, there is an indefinite number of pairs of loads which will give the same minimum total input. This can be seen by examining the curve for a total of 11. Any load on A between 6 and 8 will give 16.7 for the combined input.

The incremental rates of 2 units of different type or capacity will often be unequal at minimum loads, in which case there will be a range of total output during which the incremental rates cannot be kept the same. If 2 units are at minimum output it is naturally best to take additional load on the one with the lower incremental rate until the point is reached at which the incremental rates are equal. From then on, the 2 units should be loaded to keep the incremental rates equal until the maximum output of one unit is reached.

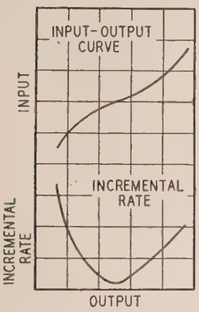
Effect of Decreasing Incremental Rates

It has been assumed heretofore that the incremental rate is always constant or increasing as the load on a unit increases. When this is true, the point at which the incremental rates of 2 units are equal always corresponds to a minimum input; and for any total output there can be only one pair of unit loads for which the incremental rates are equal, with the exception discussed above.

If one unit has a range through which the incremental rate decreases as load increases, for any total load there may be 2 or more pairs of unit loads

at which the incremental rates are equal. Any of these may correspond to a minimum, a maximum, or a point of inflection according to whether the sum of the *slopes* of the *incremental rates* (hence the sum of the second derivatives of the input-output curves) is respectively positive, negative, or zero. Thus there may be no mathematical minimum in the range of possible operation, or there may be more than one, in which case computation of both may be necessary to pick the correct one. Furthermore, when there are one or more mathematical minima there may yet be a pair of loads—the minimum or maximum load on one machine will be one of them—for which the total input is less than at the mathematical minimum.

There are several classes of curves which have this ambiguity. A curve may be smooth and have a point of inflection of curvature, such as is illustrated in Fig. 4. Its incremental rate curve is continuous and has a mathematical minimum. In Fig. 5 is shown a curve which is continuous but has a discontinuous incremental rate. Over any region in which the incremental rate is continuous, it is also increasing with the output. In passing through the points of discontinuity, the incremental rate de-



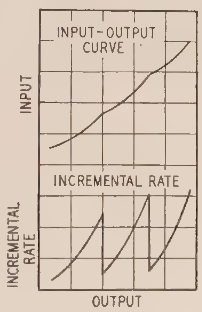


Fig. 4 (left). Input-output curve having point of inflection, and corresponding incremental rate curve

Fig. 5 (right). A continuous input-output curve having a discontinuous incremental rate curve

creases greatly resulting in a saw-tooth appearance.

The problems encountered in determining the correct load division when one of the input-output curves has the characteristics as shown in Fig. 4, are illustrated in Fig. 6. Input-output curve A is continuous and has a continuous incremental rate (curve AA) which always increases. Input-output curve B is continuous but has a point of inflection of curvature. Its incremental rate (curve BB) is continuous, decreasing to a mathematical minimum and then increasing. The family of curves show the combined input for all possible load divisions for various values of combined output. Each curve of this family represents a constant value of combined output and shows the combined input plotted against the output of machine A. It is evident from inspection that some of these curves have mathematical minima, some have minima and maxima and some have neither. The loci of *mathematical* minima and maxima are shown, as well as the locus of the *actual* minima. It will be noted that the loci of actual and mathematical minima coincide only for combined outputs exceeding 69. For combined outputs below that value, the actual minima are obtained when machine B is operated at minimum output even though by so doing the machines are not operating at equal incremental rates.

Characteristics of Input-Output Curves

It is well to note at this time that the analysis of Appendix A is based on 3 assumptions, namely:

1. That the input-output curves are continuous.
2. That the derivative or incremental rate curves are continuous.
3. That the value of incremental rate always increases as the output increases.

In many cases the input-output curves representative of power plant equipment do not fulfill the above conditions, and hence it is important to study the types of curves that may occur in actual practice and their effect on load division. The input-output curves which are important in power plant computation can be divided into 2 classes, namely, continuous curves and discontinuous curves. The distinguishing characteristic is the fact that at certain parts of the discontinuous curve there is a sudden increase or decrease in the input with no change in output.

Continuous curves may be further subdivided into those which consist of *one* smooth curve (see curve A, Fig. 2) and those which are formed from 2 or more *intersecting* smooth curves. (See curves B and C, Fig. 2.) The input-output curve for a single boiler is an example of the former, while those of most turbines are of the latter class. It can be seen that

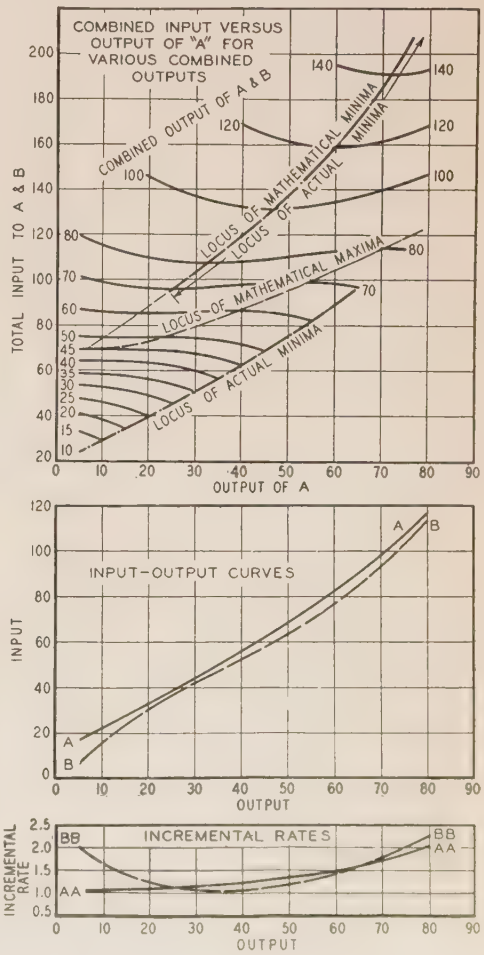


Fig. 6. Load division between 2 units having continuous incremental rates, one with and the other without decreasing values

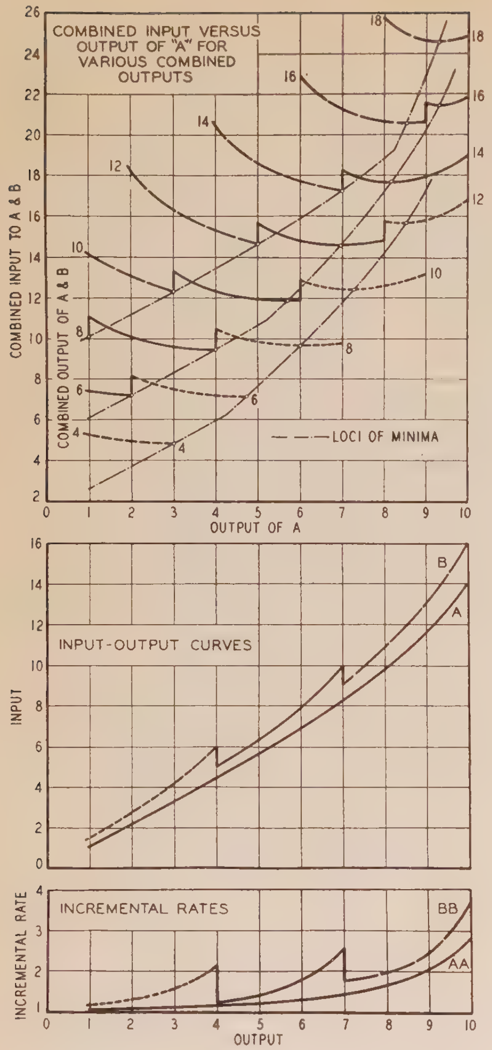


Fig. 7. Load division between 2 units, one having a continuous incremental rate curve with no decreasing values, the other having a discontinuous incremental rate curve with decreasing values

the distinguishing feature of these curves is the shape of the first derivative. In the case of curve A of Fig. 2 the first derivative is also a continuous curve whereas curves B and C have discontinuous first derivatives. Curves AA, BB, and CC of Fig. 2 show the first derivatives of curves A, B, and C, respectively. It should be noted that for input-output curves of the type shown by curves B and C, there will be 2 values for the first derivative, at any point of intersection of adjacent intervals, depending upon the direction from which the point is approached.

Discontinuous Input-Output Curves

When the input-output curve is discontinuous, its incremental rate curve is usually discontinuous at the same points. The incremental rate may always increase, may decrease in passing the points of discontinuity, or may decrease during a range in which it is continuous. In any case, incremental rates alone are not sufficient to determine the division of load which will give the least input. There may be several mathematical minima to be investigated. The actual minimum combined input may not correspond to a pair of loads having equal incremental rates, but it will then correspond to minimum or maximum output of a machine, or to a point of discontinuity in one of the input-output curves.

In Fig. 7 is shown 2 input-output curves, one of which is discontinuous and has an incremental rate curve which is discontinuous at the same points. The other input-output curve and its incremental rate are continuous. The curve net is similar to those of Figs. 3 and 6. Loci of the points of minimum input corresponding to operation in each of the 3 continuous ranges of curve B, are shown. The actual minimum combined input may be on any of the 3 loci.

Use of Approximate Input-Output Curves

As is evident from the discussion thus far, the general rule that the total input will be a minimum when 2 or more machines in parallel operate at outputs corresponding to equal incremental rate values, is invariably true only for those types of input-output curves which are continuous and whose respective incremental rates have no decreasing values with increase in output. If these conditions do not exist, incremental rates alone are not sufficient to determine the load division for most efficient operation. Hence, in order to simplify computations wherever it is possible to do so without introducing serious deviation from the actual operating characteristics of the equipment, input-output curves which are discontinuous or whose incremental rates decrease with increasing load, should be replaced by continuous curves with never-decreasing incremental rates.

The manner by which this can be done without introducing more than a negligible error will be indicated in the subsequent discussion relating to the application of incremental rates to the equipment of the boiler and turbine rooms.

Application to the Boiler Room

Methods of Load Division

There are 3 methods commonly used in dividing load among boilers. These are:

1. Division of load among the boilers such that each one is steaming at the same percentage of its rated boiler horsepower even though they may have radically different maximum capacities and performance characteristics.

2. Division of load among the boilers such that their efficiencies are equal.

3. Division of load among the boilers such that they operate at equal incremental rates.

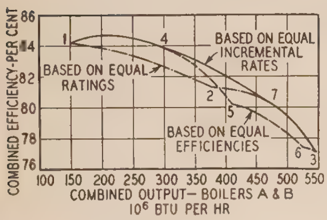
It has been shown above that the fundamentally correct method of load division is the one based upon equal incremental rates.

In Fig. 8 are shown the combined efficiencies, and in Fig. 9 the loading curves, resulting from the division of load by each of the 3 methods, between 2 boilers of different size and performance characteristics.

The performance curves for these boilers are shown in Fig. 10 and Fig. 11. Under the method of loading by equal per cent ratings, both boilers are loaded simultaneously until boiler A reaches maxi-

mum output. This range corresponds to the portion of the curve marked 1–2 in Fig. 8 and Fig. 9; between points 2 and 3 boiler A operates at maximum capacity while boiler B supplies the remainder of the load. By the equal efficiency method, boiler A is held at minimum output while boiler B picks up the additional load until its efficiency is reduced to that of boiler A. This is represented by the portion of the curve between points 1 and 5. From point 5 the boilers are loaded simultaneously until boiler B reaches its maximum output at point 6. From 6 to 3 boiler A takes the additional load. By the incremental rate method, boiler A remains at minimum output while boiler B picks up the additional load until at point 4 its incremental rate is equal to that of boiler A. In the range from point 4 to point 7 the boilers have equal incremental rates; from point 7, at which boiler A reaches maximum, to point 3, boiler B takes all the additional load.

The curves in Fig. 8 show that at no time is the combined efficiency based upon incremental rate loading exceeded by the efficiency obtained by either of the other methods. In the range of output indicated between points 1 and 4 the boilers cannot be operated at outputs corresponding either to equal incremental rates or equal efficiencies. Similarly, in the range between points 7 and 3 neither the per cent ratings nor the incremental rates corresponding to the respective outputs can be equal. This explains the coincidence of the curves in those ranges.



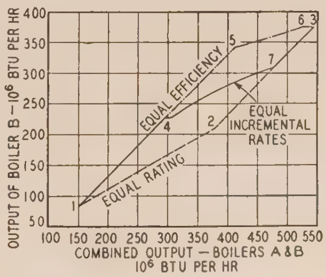


Fig. 8 (left). The combined efficiency of 2 boilers for 3 methods of load division

Fig. 9 (right). Effect of method of load division on the loading of a boiler

In Fig. 8 it is shown that considerable economy is obtained by using the incremental rate method in preference to either of the others.

Boiler Performance Data

In order to apply incremental rates to the operation of a boiler room it is necessary to have performance data for each type of boiler. The efficiency, steam temperature, and feedwater temperature curves, and the maximum and minimum steaming rates should be determined. In addition, whenever it is possible, the consumption curves of steam and electric auxiliaries for each type of boiler should be obtained.

Boiler Efficiency Curve

Boiler efficiency curves are usually obtained from tests. It is desirable, however, that the boiler efficiency used in load division shall represent normal operating conditions, and since tests are generally conducted under conditions most favorable to the boiler, some adjustment is usually necessary. Under normal operating conditions the boiler will become dirty, settings will become leaky, fuel bed conditions will not be watched so closely as on a test because an attendant will usually have to operate more than one boiler, and will not have the benefit of continuous flue gas analysis.

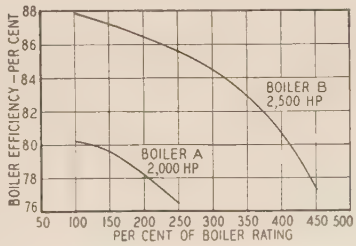
There are 2 practical methods which can be used to determine the relation between boiler efficiencies under test and operating conditions:

1. Since a boiler is usually cleaned thoroughly at periodic intervals, a simple test conducted after the boiler has been in operation for half the usual period between cleanings, will give the average operating performance. The boiler should be operated by the attendants normally assigned to it, without giving it special attention. Constant load should be maintained and sufficient readings taken to determine the efficiency.

2. By comparing the average boiler efficiency obtained over a given period of operation, with the "bogey" average efficiency derived by integrating the test values over a boiler load duration curve for the period. The load duration curve can be easily prepared if the boiler is equipped with reliable steam or feedwater meters. Steam pressures and temperatures, feedwater temperatures, and the calorific value and quantity of coal burned would be needed. The period selected should be in the middle of the interval between cleanings.

The second method is not so desirable as the first because: (a) It may be difficult to determine a reliable value of the actual average efficiency. (b) A single correction factor must be applied over the entire range of boiler output, whereas it is probable that the correction factor varies with the boiler output. (c) Losses caused by load fluctuations should not influence boiler load division; this method includes these losses and thereby may result in too high an operating factor.

The application of the second method and a comparison of both methods are shown in Table II and Fig. 12. Curve A shows the efficiency under test conditions, curve B the operating efficiency under normal conditions determined by applying a constant



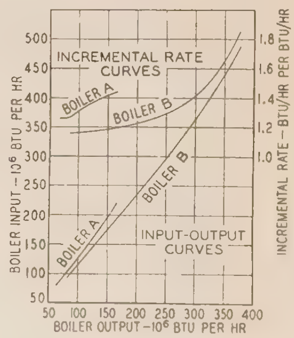


Fig. 10 (left). Efficiency curves of boilers A and B plotted against output in per cent of boiler rating

Fig. 11 (right). Performance curves of boilers A and B plotted against output in heat units

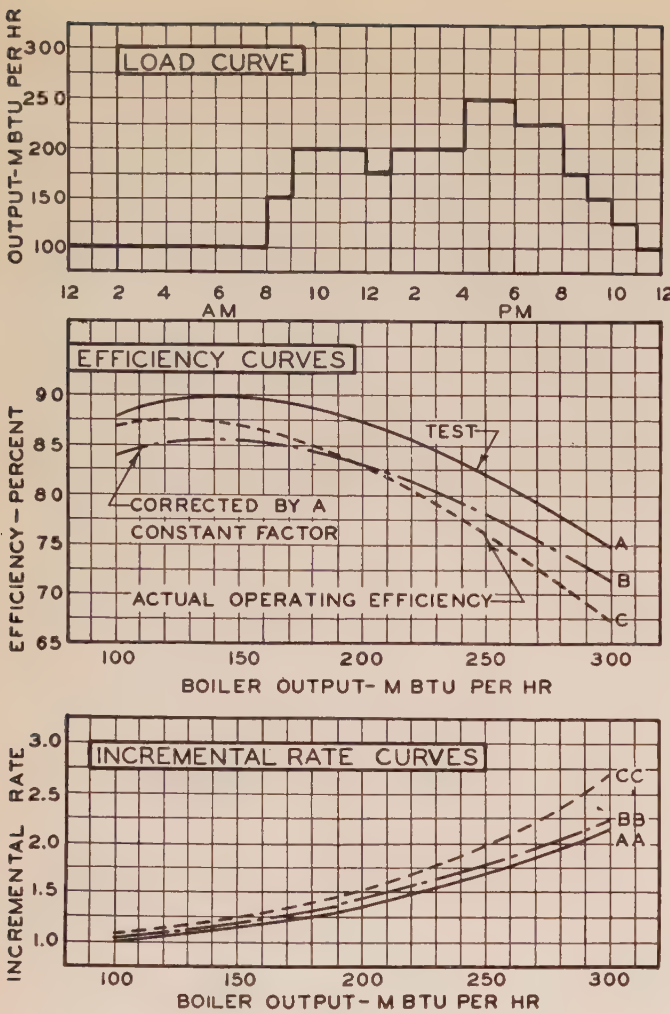


Fig. 12. Determination of operating boiler efficiency from test efficiency using a constant and a variable factor

M Btu indicates million Btu

factor to the test efficiency, and curve C shows the actual operating efficiency determined by test as outlined in method 1. Curves AA, BB, and CC show the corresponding boiler incremental rates.

In addition to applying an operating factor, it may be desirable to correct the test efficiency curve for the effect of steam temperature variation on turbine efficiency, and for the power consumption of the boiler auxiliaries. The fact that turbine economy increases considerably with increased steam temperature makes it apparent that if a turbine can be supplied with steam from either of 2 boilers which have equal efficiencies but different steam temperatures, the boiler with the higher steam temperature will require less heat input than the other, for a given turbine output. Similarly, if 2 boilers have the same efficiencies, but the power consumptions of their auxiliaries are different, the boiler with the lower power consumption will have the higher net efficiency.

Since the boiler and turbine performance corrections for any station are so intimately related, the detailed analysis will not be included here, but will be treated in the discussion of station performance.

Maximum and Minimum Steaming Rates

The determination of the maximum steaming rate of an individual boiler presents no difficult problem since a maximum capacity run is usually made during the boiler test. When a group of boilers are served by the same fan equipment or stack, the capacity of this equipment may not permit all of the boilers to be operated at their maximum individual steaming rates. Furthermore, high superheat, increased maintenance costs, or combustion conditions such as excessive carbon monoxide loss or smoke, may limit the operating maximum.

The minimum steaming rate at which a stoker-fired boiler will be operated before being banked will depend upon the practice at any particular station. The more important of the factors which usually determine the minimum steaming rate are the ability to maintain fuel bed conditions, the efficiency, and the responsiveness to sudden demands which may be made upon the boilers while operating at such a low rate. For pulverized coal boilers the minimum rate of operation will usually depend upon the minimum capacity of each burner and whether or not some of the burners can be cut out.

Banked Boilers

During the daily load cycle of most steam generating stations, there is a period in which some boilers are banked. This may be done to eliminate the necessity of operating boilers below their minimum steaming rates or to increase the over-all boiler room efficiency. A study should be made to determine what boilers to bank and when.

The term banking as used in this discussion means the operation of a boiler with no steam output. For stoker-fired boilers, the banking loss is the amount of heat input necessary to maintain the fuel

Table II—Derivation of Correction Factor for Adjusting Boiler Test Efficiency to Operating Conditions

Time	Duration Hours	Output, Million Btu Per Hour	Output, Million Btu Total	Test Eff. Per Cent	Bogey Input, Million Btu
12–8 a.m.	8	100	800	88.1	908.1
8–9	1	150	150	90.0	166.7
9–12	3	200	600	87.3	687.3
12–1 p.m.	1	175	175	89.0	196.6
1–4	3	200	600	87.3	687.3
4–6	2	250	500	82.0	609.9
6–8	2	225	450	85.0	529.4
8–9	1	175	175	89.0	196.6
9–10	1	150	150	90.0	166.7
10–11	1	125	125	89.7	139.4
11–12	1	100	100	88.1	113.5
Totals	24		3,825		4,401.5

Bogey overall efficiency $= \frac{3,825}{4,401.5} \times 100 = 86.9$ per cent

Total coal actually burned, 24 hr, 327,560 lb

Btu per pound of coal, 14,100

Actual boiler input, 24 hr, 4,618.6 million Btu

Actual efficiency, 24 hr $= \frac{3,825}{4,618.6} \times 100 = 82.8$ per cent

Correction factor $= \frac{82.8}{86.9} = 0.953$

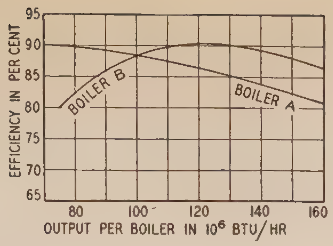


Fig. 13. Efficiency curves used to illustrate boiler banking sequence

bed in a satisfactory condition. For pulverized-coal boilers the total banking loss is the heat input required either to maintain or to restore the boiler setting to its normal operating temperatures when the boiler starts steaming; the average hourly banking loss is then the total loss divided by the duration of the banked period.

Two types of boiler efficiency curves which are important in determining banking practice are illustrated in Fig. 13. The highest efficiency for type A boiler occurs at the minimum steaming rate, whereas for type B boiler, this occurs at a steaming rate greater than the minimum.

When all of the boilers are identical and have the characteristics of type A of Fig. 13, as many boilers should be kept steaming at all station loads as can be operated at or above the minimum rate. The total loads, therefore, at which boilers should be banked are multiples of the minimum steaming rate of a single boiler.

Consider next a group of boilers which are identical, and have the characteristics of type B of Fig. 13. The proper loads at which to bank such boilers should be determined by the points of intersection of the over-all efficiency curves for successive combinations of steaming and banked boilers.

In Figs. 14 and 15 are shown the over-all efficiency and input-output curves in the banked boiler region for groups of each type of boiler. The solid lines indicate performance under proper operation. It will be noted that in the case of the type A boilers, both the input-output and efficiency curves are discontinuous at the points at which boilers are banked. For type B boilers, the input-output and efficiency curves are continuous, because as a boiler is banked the increase in banking loss is exactly neutralized by the decreased input to the steaming boilers resulting from their operation at a higher efficiency.

When groups of boilers operated in parallel differ in size and performance characteristics, it will be necessary to determine not only when to bank boilers, but which ones to bank to give the maximum efficiency. Often there is some operating reason for banking certain boilers in preference to others; if not, the various combinations should be computed to determine which gives the best results. The

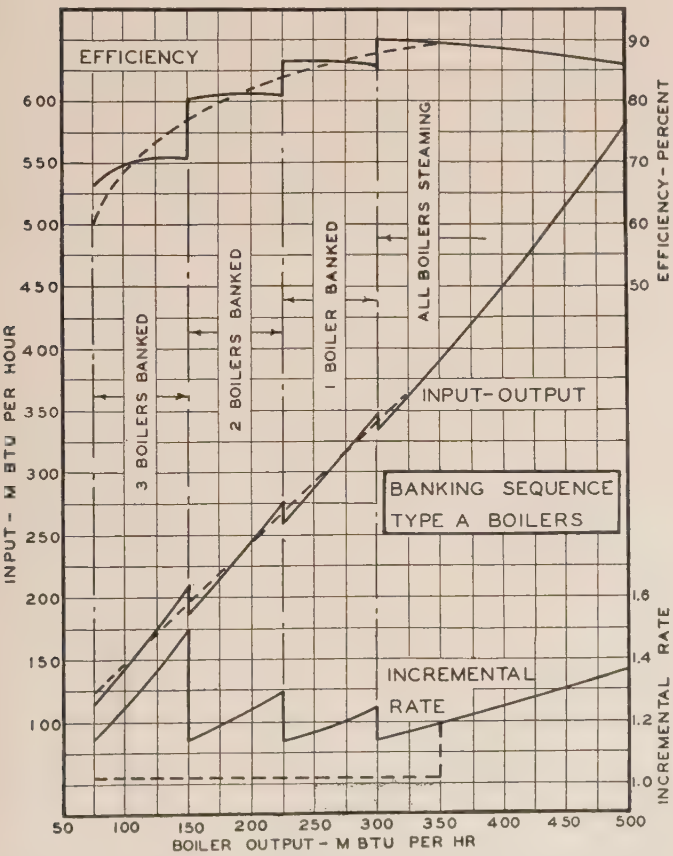


Fig. 14. Banking sequence of boilers with maximum efficiency at minimum output (Type A)

Method of determining average incremental rate curve for banking period
M Btu indicates million Btu

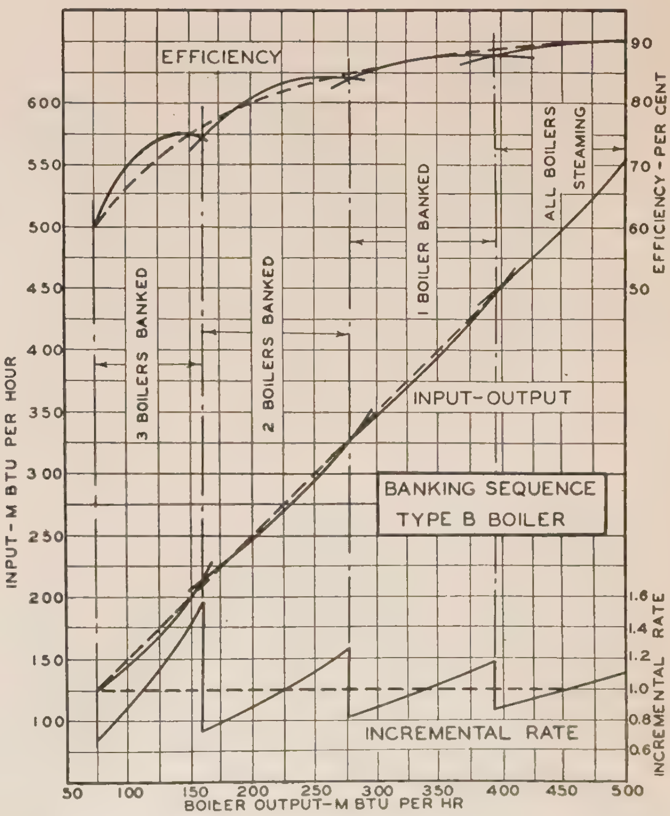
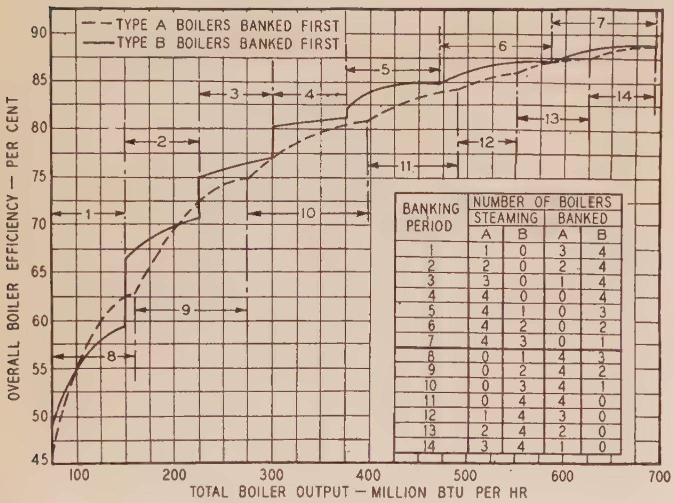


Fig. 15. Banking sequence of boilers with maximum efficiency at an output greater than minimum (Type B)

Method of determining average incremental rate curve for banking period

factors that determine which type of boiler to bank are the relative banking losses, the relative magnitudes and shapes of the efficiency curves, and the number of boilers of each type. It may be stated that, if the size, maximum efficiency, minimum steaming rate, and banked loss of each type of boiler are substantially the same, it will usually be more efficient to bank boilers whose efficiency



BANKING PERIOD	NUMBER OF BOILERS STEAMING A	STEAMING B	BANKED A	BANKED B
1	1	0	3	4
2	2	0	2	4
3	3	0	1	4
4	4	0	0	4
5	4	1	0	3
6	4	2	0	2
7	4	3	0	1
8	0	1	4	3
9	0	2	4	2
10	0	3	4	1
11	0	4	4	0
12	1	4	3	0
13	2	4	2	0
14	3	4	1	0

Fig. 16. Effect of boiler banking sequence on overall boiler efficiency

curves are of type B rather than type A, Fig. 13.

In Fig. 16 are shown 2 series of efficiency curves obtained in the banked boiler region for 8 boilers, 4 of which have the characteristics of boiler A and 4 of boiler B of Fig. 13. Banking all of the type B boilers before any of the type A boilers is shown by the solid curve; banking all of the type A boilers first is shown by the dotted curve. The difference in performance shows that if the banking period is of considerable duration, the use of the correct sequence of banking is important.

Boiler Room Incremental Rate With All Boilers Steaming

After the operating efficiency curve has been established, the boiler incremental rate can easily be determined by computing the inputs corresponding to a series of values of boiler output and dividing the differences between successive values of input by the corresponding differences of output.

In Fig. 17 is illustrated the method of deriving the incremental rate curve for any group of similar boilers from the incremental rate curve of an individual boiler. Thus, at an incremental rate value of 1.5, the corresponding outputs for 1, 2, 3, and 4 boilers are at points A, B, C, and D, respectively. The outputs at points B, C, and D are multiples of the output for one boiler at point A depending upon the number of boilers in the group. By repeating the process for other values of incremental rate, sufficient points are obtained for plotting the curves.

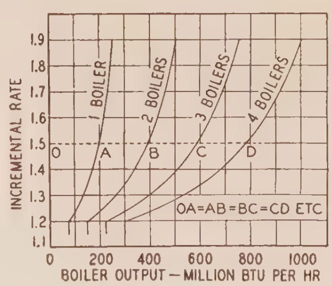
When boilers or groups of boilers are dissimilar, the over-all incremental rate curve for any combination is obtained in the manner shown in Fig. 18. For the purpose of illustration, boilers with different values of minimum output are shown. Since there is a range of output of boiler B during which the incremental rates are less than that corresponding to the minimum output of boiler A, boiler B will first be loaded until its output corresponds to the minimum incremental rate value of boiler A, namely, 1.20. The incremental rate curve for the combination of boilers has, therefore, the same values as the curve for boiler B during the range in which only boiler B is loaded. That portion of the combined curve between points 1 and 2 is obtained by adding the minimum output of boiler A to that of boiler B and plotting the total output against the value of incremental rate corresponding to the output of boiler B.

In the range between points 2 and 3 both boilers are loaded incrementally. Thus the output at point 7 is the sum of the outputs at points 5 and 6.

After boiler B reaches its maximum output, any additional load is supplied by boiler A. That portion of the curve between points 3 and 4 has incremental rate values equal to those for boiler A.

Incremental Rate in Banked Region

If, in a group of similar boilers, some are steaming and some are banked, then the *actual* incremental rate of the group is equal to the incremental rate of an individual steaming boiler; since the input to the banked boilers is constant, it has no effect upon the actual incremental rate of the group. As the combined output of the group increases there is a point at which it is more economical to start steaming one of the banked boilers. At this point the incre-



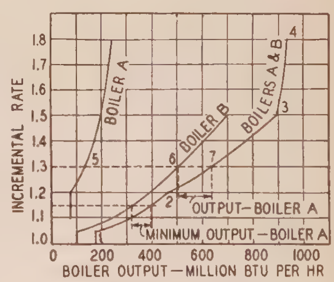


Fig. 17 (left). Method of deriving incremental rate curve for a group of similar boilers

Fig. 18 (right). Method of deriving combined incremental rate curve for dissimilar type boilers

mental rate decreases and in many cases the input also decreases. Adding another boiler allows a reduction in the individual outputs of the steaming boilers and hence a reduction in the incremental rate; if there is a decrease in total input it is because the reduction in input to the group of steaming boilers is greater than any increase in the input to the boiler brought up from bank.

Since it is desirable that the incremental rate of the group shall never decrease as the output increases, a modification of the input-output curve during the banked region should be made. An average curve should be drawn, having an incremental rate curve which never decreases. In Fig. 14 and Fig. 15 are shown the actual and average input-output curves with the corresponding efficiency and incremental rate curves for the 2 types of boilers of Fig. 13. It will be noted that in Fig. 14 the incremental rate curve corresponding to the *average* input-output curve is much lower than the actual incremental rate curve during the banked boiler period.

From the input-output curve of Fig. 14, consider the conditions when a single boiler, and again when all the boilers are operating at minimum output. These are indicated in the following tabulation:

Number of steaming boilers	1	4
Number of banked boilers	3	0
Minimum output, million Btu per hour	75	300
Input at minimum output, million Btu per hour	112.5	342.5
Incremental input, million Btu per hour	230	
Incremental output, million Btu per hour	225	
Incremental rate (230 ÷ 225)	1.02	

It is seen from the above that as the total output is increased from that of minimum to a value which permits the steaming of all boilers at a minimum, the change in input is 1.02 times the change in output. This value represents the *average* incremental rate for the transition period during which boilers are taken off bank. It is now obvious that an average drawn through the discontinuous actual incremental rate curve would be undesirable for the reasons that there would be decreasing values of incremental rate with increased output and that such an average would not be representative of actual operation during the period when boilers are taken off bank.

In drawing an average through the discontinuous portion of the input-output curve, a straight line was used having a slope or incremental rate of 1.02.

In Fig. 15, also, the average incremental rate was obtained from the average drawn through the input-output curve. In this case, the average incremental rate approximates an average line drawn through the discontinuous portion of the incremental rate curve.

When there are 2 or more dissimilar groups of boilers, the banking sequence should be determined to give the highest efficiency. An average input-output curve should then be drawn in the banked boiler range and the corresponding incremental rate computed.

The number of boilers available in a station usually varies from time to time. Since this affects both the incremental rate and efficiency, for any given boiler room output, curves should be computed for those combinations which are likely to occur.

Effect of Coal Cost

If the cost of fuel burned is the same for all boilers, operation of the boiler room to give the minimum heat input also makes the cost of fuel a minimum. In such a case it is sufficient to express the values of input and output in Btu per hour.

When all the boilers do not use the same type or grade of fuel, there usually is a difference in the cost of the fuel per Btu. In such a case, load division which gives the minimum heat input does not result in minimum cost of fuel.

Instead of an input-output curve expressed in Btu per hour, an input-output curve whose input is expressed as fuel cost in dollars per hour can be used. The corresponding incremental fuel cost curve can then be expressed as (cents per hour) per (million Btu per hr), and the boilers be loaded so as to keep their respective incremental fuel costs the same.

In practice it is more simple to adjust the boiler incremental rate curves for difference in coal cost than to convert the input-output curves. Consider 2 boilers which burn different grades of coal having the following costs:

Boiler	*A*	*B*
Cost of coal per short ton	\$3.60	\$4.25
Btu per pound of coal	13,000	14,000
Cost of coal per million Btu	13.85	15.18

Since the coal burned by boiler *A* is cheaper than that burned by boiler *B*, adjustment can be made by multiplying the incremental rate values of boiler *A* by the ratio $\frac{13.85}{15.18} = 0.912$ or those of boiler *B* by the ratio $\frac{15.18}{13.85} = 1.096$.

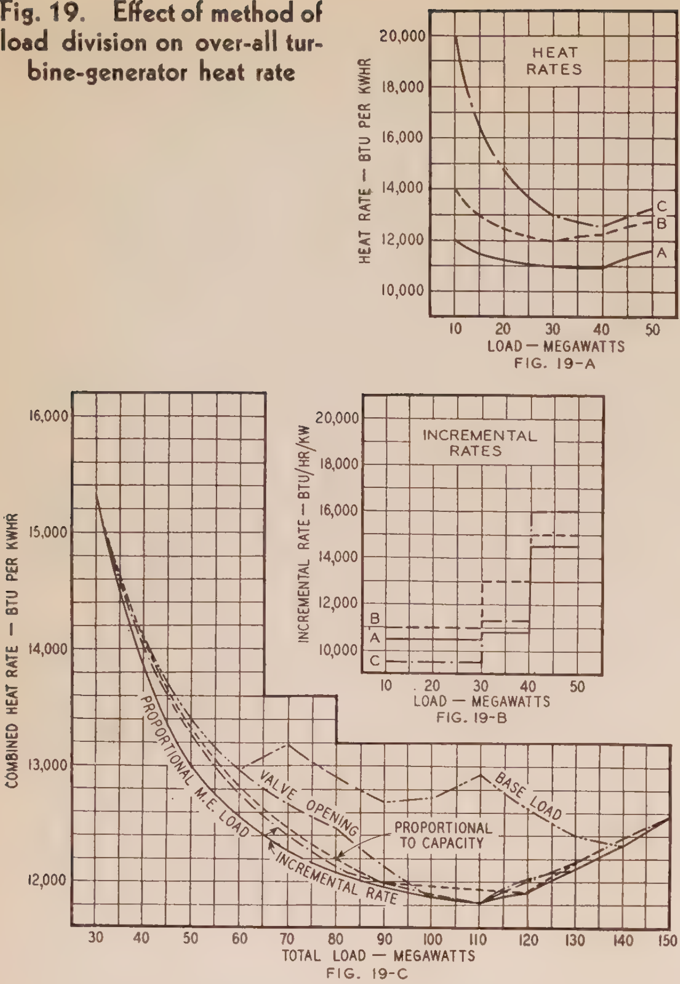
Application to the Turbine Room

Use of incremental rates in scheduling turbine room operation is more complex than in the boiler room. There is a much wider choice as to the number of units to be run and the sequence of adding units as the load increases. Whereas the number of boilers in service is usually determined by the number out for repairs or overhauling, turbines are on the line part of the day or all the day as the station load demands. In the boiler room the problem is how much load shall each type boiler carry. In the turbine room it is how many units shall be put in service; then which units shall be used; finally, how shall the load be divided among them.

The variation in types of turbine units installed in a given station is often greater than the variation of the boilers of the same station. Each unit may be different in size and type. There may be impulse and reaction turbines, straight condensing and extraction, one-stage bleed and multi-stage bleed, constant feedwater temperature and variable feedwater temperature, single-cylinder, tandem-compound and cross-compound.

The heat balance may be further complicated by the type of auxiliaries used. If these are electric, there may be 3 sources of low voltage power: house-turbines; house-generators on the same shafts as the main turbines; and house-transformers may be used. One station may use all 3 sources.

Fig. 19. Effect of method of load division on over-all turbine-generator heat rate



If steam auxiliaries are used, part or all of the exhaust steam may be used to heat feedwater. This is done in many older stations where the main units are straight condensing. In some modern plants, steam auxiliaries are used in combination with extraction type units, and the exhaust, as well as bleed steam, is used for feed heating. Since the pressure of the exhaust steam is approximately atmospheric, it will usually enter the cycle between bleed steam at higher and lower pressures; this makes the turbine performance dependent upon the amount of exhaust steam.

Methods of Turbine Load Division

Results obtained by 5 of the methods most commonly used in distributing load among turbines are illustrated in Fig. 19*C*. The 3 turbines whose heat rate and incremental rate curves are shown in Fig. 19*A* and Fig. 19*B*, respectively, are loaded from minimum to maximum and the combined heat rate curves are shown. (The proper number of units to run at a given load, although important, is not considered at this point, but will be taken up later.) It will be noted that although unit *A* has the lowest heat rate, unit *C* has the lowest incremental rate from minimum load to the first valve point.

The 5 methods used are described below:

1. Incremental rates. The load is divided to keep the turbines operating at equal incremental rates.

2. Base load. By this method, until the most efficient unit is loaded to capacity, the other units are operated at minimum loads. The other units are successively loaded to capacity in the order of their efficiencies. Thus the order in which the 3 units shown in Fig. 19*A* would be loaded to capacity is *A*, *B*, and *C*.

3. Valve opening. The units are successively loaded in ascending order of their heat rates, to their most efficient points. When all units are operating at their most efficient loads, they are loaded to capacity in the same order. Thus for the units of Fig. 19*A*, unit *A* would first be loaded to 40 megawatts (one megawatt is one million watts, or 1,000 kw), unit *B* to 30 megawatts, and then unit *C* to 40 megawatts. The units are then loaded to 50 megawatts each in the same order, *A*, *B*, and *C*.

4. Proportional to capacity. The loads on the units are in proportion to their rated capacities. Since the units of Fig. 19*A* are all of 50-megawatt capacity, they would be loaded equally.

5. Proportional to most efficient load. By this method, the loads on the units are kept in proportion to the loads corresponding to their lowest heat rates. After the units have reached their most efficient points, the additional load on each is made proportional to the difference between the rated capacity and the most efficient load. Thus the loads on units *A*, *B*, and *C* of Fig. 19*A* would be in the ratio of 40:30:40, respectively, until the total load was 110 megawatts. Any increase above this value would be divided among the units in the ratio of (50–40):(50–30):(50–40).

Comparison of the results of the 5 methods as applied to the 3 units used in the illustration clearly shows that the incremental rate method always gives the lowest over-all turbine heat rate, and is never equaled by any of the other methods except when the load division is the same. Although the 2 methods based upon proportional loading will rarely give the best distribution, they would apparently be fairly reliable for load division in a small standby station, where detailed performance data cannot be obtained. The valve opening and base load methods show up unfavorably in this illustration. Under some circumstances they would come much closer to the correct loading, but it may be stated that if there are enough data available to make either of these 2 methods trustworthy, there are enough to use the incremental rate method, by which the correct results can be obtained.

Turbine Performance Data

In order to apply incremental rates to the operation of a turbine room, performance data from which the heat rate curve for each turbine can be established, are necessary. The heat rate curves should represent the performance of the turbines under actual operating conditions of steam pressure and temperature at the throttle, vacuum at exhaust corresponding to the particular circulating water temperature under consideration, and the particular heat balance cycle. Data determined by tests under actual operating conditions are the most reliable and should be obtained whenever possible. Guarantee data should not be used if it can be avoided since frequently the actual performance is considerably different.

Tests on extraction type units should be run under normal extraction conditions. An approximation of feed heating performance can be calculated from a careful nonextraction test, but it is not so reliable as an actual extraction test. The calculated performance may be substantially correct in

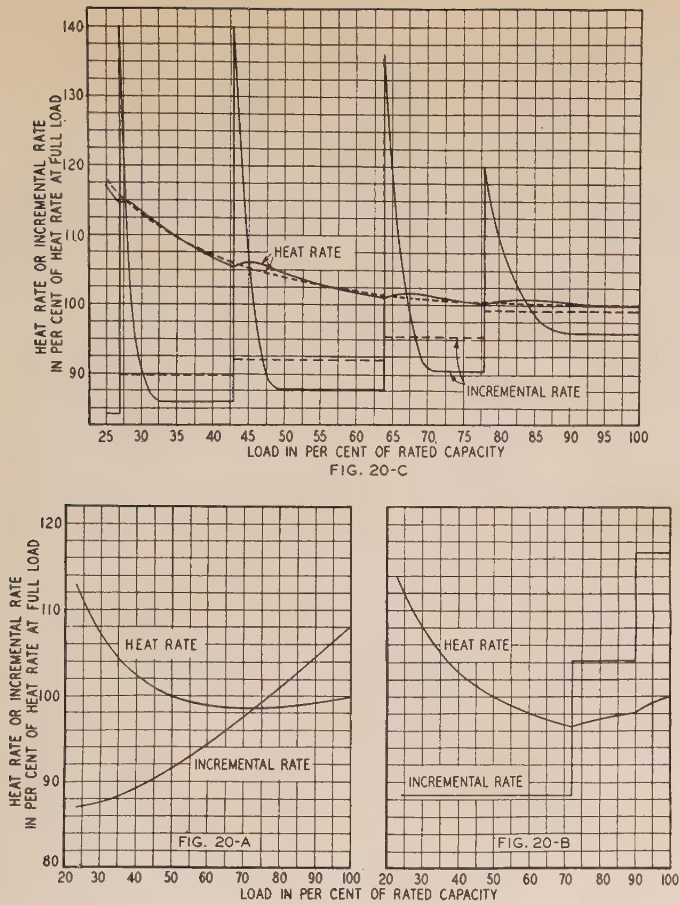


Fig. 20. Typical performance curves of turbine-generators

magnitude and yet show a very incorrect incremental rate.

Additional desirable data are the power consumption of steam and electric auxiliaries, curves showing operating vacuum at varying circulating water inlet temperatures, and correction curves for variation of steam pressure and temperature at the throttle and vacuum at exhaust. The use of these data to correct the turbine room performance to actual operating conditions will be discussed later.

Turbine Heat Rate and Incremental Rate Curves

Turbine heat rate curves usually fall into one of the 3 types shown in Fig. 20*A*, *B*, and *C*. In Fig. 20*A*, the heat rate curve is one continuous smooth curve; its incremental rate is continuous, smooth, and always increases with the load. In Fig. 20*B*, the heat rate curve is continuous but has definite breaks at the loads at which valves start to open. The incremental rate curve is discontinuous, having step-like increases at the loads corresponding to the break points of the heat rate curve. Between valve openings, the incremental rate is constant.

In many recent large turbine installations, heat rate curves are obtained similar to the solid curve shown in Fig. 20*C*. The heat rate curve is continuous with breaks at the valve points. Over a short load range following each valve point, the heat rate curve has a slight hump, which causes the incremental rate to increase suddenly and then gradually decrease to a constant value until the next valve point is reached. The difficulty in using an incremental rate curve of this type lies in the fact that since there are several loads corresponding to the same incremental rate, considerable computation may be required to determine the division of load that will result in the minimum input. The simplest case to consider is that of 2 identical machines with incremental and heat rate curves represented by the solid curves in Fig. 20*C*. Suppose a total load of 110 is to be divided between the 2 machines, then the incremental rates for each machine will be equal for the following combinations of loads: (27, 83), (28.25, 81.75), (44.5, 65.5), (46, 64), and (55, 55). (At the break points such as at 43 and 64, the incremental rate is assumed to contain all the values on the vertical lines.) Figure 21 shows for various total loads, the heat rates (in per cent of the heat rate of one machine at maximum load) plotted against the per cent load on one machine, and indicates that the actual minimum input for the 110 load corresponds to the combination (46, 64). It is important to note that for machines having this type of heat rate curve, the minimum total input *is not obtained when the load is equally divided between 2 or more identical machines.* In fact, for a total load of 170 (see Fig. 21) dividing the load equally actually gives the highest input of any possible combination. Since the 2 machines are identical, each curve of Fig. 21 is symmetrical about the load corresponding to half of the combined load. The circles show, for each total load, the combination which gives the minimum input. It will be noted that, for all of the loads worked out, the best combination is that in which one of the machines is operating at the break point which is most nearly equal to one-half of the total load.

In the more complicated case involving several machines which are not identical it will be found that the minimum input is obtained when all of the machines except one operate at valve points. To facilitate the selection of the best combinations,

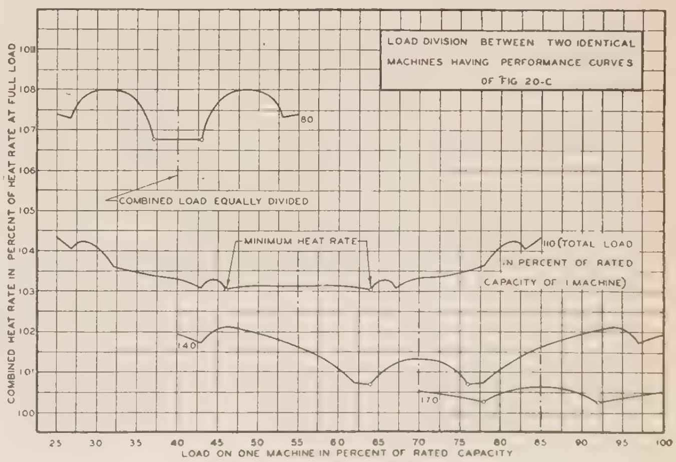


Fig. 21. Effect of load division on over-all efficiency of 2 identical turbine-generators having performance curves of Fig. 20C

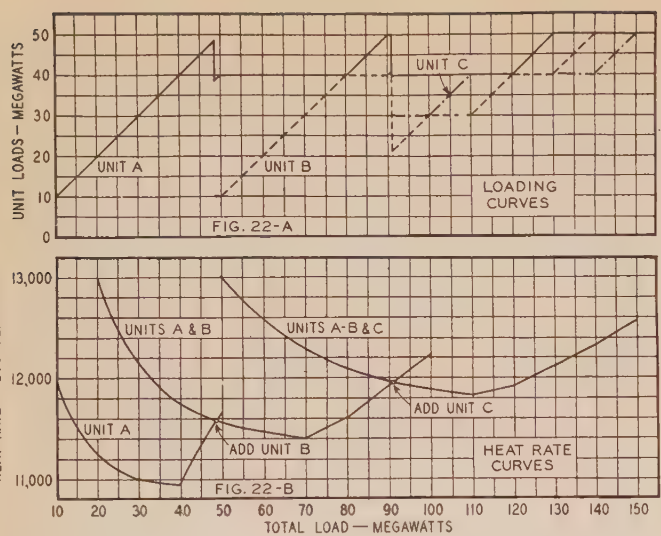


Fig. 22. Determination of loading sequence for 3 turbine-generators

adjusted heat rate and incremental rate curves are drawn similar in shape to those shown in Fig. 20*B*. The average incremental rates between valve points are plotted; these are obtained by dividing the differences in successive inputs corresponding to the valve-opening loads, by the corresponding differences in output.

The total load is then divided among the machines as if the average were the actual incremental rate with the exception, however, that all but one machine are operated at valve-opening loads. The relative values of the average incremental rates indicate which machines should be operated at valve-opening loads and which machine should carry the increase in total load.

Sequence of Adding Turbine-Generators

Determination of the proper order of putting units on the line is very important. It is usually quite simple since in most stations the latest equipment to be installed is the largest and most efficient. It cannot be stressed too strongly that the problem of which unit to put on the line must be solved by considering the heat rate, rather than the incremental rate. After the unit is on the line the incremental rate becomes of greater importance, and determines the proper loading of the turbine.

By plotting the input-output curves of all the units on the same axes a direct comparison can be made. The advantage of using input-output curves rather than heat rate curves is that the relative slopes are more easily judged. Sometimes the large units may have a higher input at their minimum loads than other units at the same load. This should not be given undue weight, because it is only at low station loads that it is important. In the case of standby stations operating at low loads for a considerable portion of the time, it is best to operate those units which have the lowest inputs at minimum operating loads, unless the additional capacity of larger units is needed. When the low-load periods are of short duration the factors which influence the choice of units to be operated are relative starting losses and the possibility of increased outage of large units resulting from frequently starting them up and shutting them down.

After selecting the order, it becomes necessary to determine the station loads at which units should be added. Units should be added when economy dictates, unless safety considerations require them sooner.

A method often used in scheduling turbine loads is to run the best unit up to its point of minimum heat rate, then add another unit to take additional load. The second unit would take load until its minimum heat rate has been reached when a third unit would be added, and so on. That this method of loading will not give the best station economy can be seen by inspection of Fig. 22*B*, since the second unit would be required at a station load of 40 and the third unit at a load of 70.

It is practically always more economical to run one unit beyond its point of maximum efficiency before adding another unit. To determine the load at which it becomes more economical to add a unit it is best to plot against station load, either the combined turbine input or the heat rate for the number of units running and for an extra unit. The intersection of the 2 curves gives the load at which to add the unit. Figure 22*B* shows the heat rate curves corresponding to combinations of units *A*, *B*, and *C* of Fig. 19*A* and *B* and indicates the station loads at which units should be added. Figure 22*A* shows a loading schedule which corresponds to the most economical sequence of adding units and Table III is a complete loading schedule for the same

Table III—Turbine Loading Schedule

	1 Unit	2 Units		3 Units		
Station Load	Unit A	Unit A	Unit B	Unit A	Unit B	Unit C
10	10					
15	15					
20	20	10	10			
25	25	15	10			
30	30	20	10	10	10	10
35	35	25	10	10	10	15
40	40	30	10	10	10	20
45	45	35	10	10	10	25
48.5	48.5	38.5	10	10	10	28.5
50	50	40	10	10	10	30
55		40	15	15	10	30
60		40	20	20	10	30
65		40	25	25	10	30
70		40	30	30	10	30
75		40	35	35	10	30
80		40	40	40	10	30
85		45	40	40	15	30
90		50	40	40	20	30
91		50	41	40	21	30
95		50	45	40	25	30
100		50	50	40	30	30
105				40	30	35
110				40	30	40
115				40	35	40
120				40	40	40
125				45	40	40
130				50	40	40
135				50	45	40
140				50	50	40
145				50	50	45
150				50	50	50

combinations. The portions of the schedule between the horizontal lines correspond to correct operation; the remainder of the table would be used when the proper combinations could not be run, for safety or other reasons.

As previously mentioned, the starting losses must be considered in connection with determining the economy of adding an additional unit to the bus. This can be best illustrated by an example using the curves of Fig. 22*B*.

Suppose that 2 units are supplying a load of 90 megawatts and the station load is increased to 95 megawatts. Then an additional unit is indicated. If the 95 megawatts be supplied by 3 units, the heat rate would be 11,920 Btu per kwhr; if supplied by 2 units the heat rate would be 12,080 Btu per kwhr. For every hour that 2 machines are operated at that load there would be a loss amounting to 95,000 × (12,080 − 11,920) = 15.2 million Btu. If the starting losses of the third unit amount to 50 million Btu, then the station load of 95 megawatts must be maintained for $\frac{50}{15.2} = 3.3$ hr before the addition of the third machine can be justified.

Thus the problem resolves itself into the consideration of 2 factors:

1. The starting losses of the additional unit.
2. The duration of the additional load.

Appendix A

Derivation of Conditions for Maximum Efficiency

Following is a mathematical analysis establishing the conditions for maximum over-all efficiency when 2 units of different characteristics are operating in parallel to supply a common load.

Let

O_t = total output of the 2 units
O_1 = output of unit No. 1
O_2 = output of unit No. 2
I_t = total input to the 2 units
I_1 = input to unit No. 1
I_2 = input to unit No. 2

It is assumed that $I_1 = F_1(O_1)$ and $I_2 = F_2(O_2)$ represent 2 continuous input-output curves, and have continuous derivatives, $\frac{dI_1}{dO_1}$ and $\frac{dI_2}{dO_2}$, respectively, which always increase as O_1 and O_2 increase. Therefore the second derivatives, $\frac{d^2I_1}{dO_1^2}$ and $\frac{d^2I_2}{dO_2^2}$, and hence their sum, are always positive.

$$I_t = I_1 + I_2 \tag{1}$$

and

$$O_t = O_1 + O_2 \tag{2}$$

The problem is to determine for any given value of O_t, for example O_a, the values of O_1 and O_2 which will make I_t a minimum. Then

$$O_1 + O_2 = O_a, \text{ a constant} \tag{3}$$

$$O_2 = O_a - O_1 \tag{4}$$

$$I_t = I_1 + I_2 \tag{5}$$

Now, since its second derivative is positive, I_t will be a minimum when its derivative with respect to O_1 vanishes.

Or

$$\frac{dI_t}{dO_1} = 0 \tag{6}$$

But

$$\frac{dI_t}{dO_1} = \frac{dI_1}{dO_1} + \frac{dI_2}{dO_1} \tag{7}$$

$$= \frac{dI_1}{dO_1} + \frac{dI_2}{dO_2} \times \frac{dO_2}{dO_1} \tag{8}$$

Furthermore

$$\frac{dO_2}{dO_1} = \frac{d}{dO_1}(O_a - O_1) = -1 \tag{9}$$

Hence

$$\frac{dI_t}{dO_1} = \frac{dI_1}{dO_1} - \frac{dI_2}{dO_2} \tag{10}$$

Equating eqs 6 and 10

$$\frac{dI_1}{dO_1} - \frac{dI_2}{dO_2} = 0 \tag{11}$$

Or

$$\frac{dI_1}{dO_1} = \frac{dI_2}{dO_2} \tag{12}$$

This means that the minimum input for a given combined output is obtained when the incremental rates of the 2 units are equal. Furthermore, there is only one pair of loads for any given output at which the incremental rates will be equal.

The second and concluding part of this paper on "The Theory of Incremental Rates and Their Practical Application to Load Division" is scheduled for publication in the April 1934 issue of ELECTRICAL ENGINEERING. In the present issue, the theoretical background, the application of the method to the boiler room and to the turbine room, and Appendix A, have been given, thereby laying the groundwork for the application of the method to the generating station, which phase of the subject will be treated in the second part. The conclusion, Appendixes B, C, and D, and references to further reading also will be included therein.

Discussions

Of A.I.E.E. Papers—as Recommended for Publication by Technical Committees

On this and the following pages appear those discussions of A.I.E.E. winter convention papers that were received in complete and acceptable form at Institute headquarters up to Feb. 5, and subsequently reviewed by the various technical committees and recommended for publication. Discussions received subsequent to Feb. 5 and prior to March 1 are scheduled for publication in the April issue, subject to the recommendations of technical reviewers. It appears that these 2 groups will account for the bulk of the total discussion of the winter convention papers as published in the Aug., Nov., and Dec. 1933, and the Jan. 1934 issues of Electrical Engineering. However, discussions received after March 1 will be given the same attention as those received earlier, and will be judged on the same basis for possible publication.

Authors' formal closures are scheduled for inclusion in the April issue, and will embrace all discussions received and accepted by March 1.

This new department in Electrical Engineering marks a further step in the evolution of the unified publication plan adopted by the A.I.E.E. board of directors in August 1933, the purpose of which is to carry to every member of the Institute all technical and related material as promptly as it can be released and published. Another wish is to stimulate and facilitate a broader participation on the part of Institute members everywhere in the study and discussion of current technical papers. Therefore, members anywhere are encouraged to submit written discussion of any A.I.E.E. paper published in Electrical Engineering, which discussion will be reviewed by the proper technical committee and considered for possible publication in a subsequent issue. Discussions should be: (1) concise; (2) restricted to the subject of the paper or papers under consideration; (3) typewritten and submitted in triplicate to C. S. Rich, secretary, technical program committee, A.I.E.E. headquarters, 33 West 39th Street, New York, N. Y.

The Pitt-Westinghouse Graduate Program

Discussion of a paper by H. E. Dyche and R. E. Hellmund published in the January 1934 issue, p. 103–8, and presented for oral discussion at the education session of the winter convention, New York, N. Y., Jan. 24, 1934.

A. M. Dudley: Having been associated with the Pittsburgh-Westinghouse program since its inception, as an instructor, and having in addition worked out the requirements for his own Master's Degree, the writer has an intimate knowledge of the arrangement which stimulates him to make some practical observations on points not covered in detail by the authors.

Experience with the process of recruiting technical graduates for industry showed that there were always a number of men of high mentality who wished to take graduate work, but who financially were unable to stay in school, or who feared becoming rusty on undergraduate training if they waited too long to try their hand on practical problems. These men found in the Pittsburgh-Westinghouse combination a chance to start their professional career immediately and, at the same time, proceed with their graduate work. As a result, the graduate work was much more effective and progress toward financial independence was expedited by nearly 2 years.

Many present-day graduates are imbued with the idea so ably championed by Dean Sackett that an engineer must pursue a course of "continuous education." The Pittsburgh-Westinghouse arrangement not only encourages this, but it provides a means for capitalizing graduate study and making it count toward an advanced degree.

The arrangement stimulates older engineers whose college days are several years behind them to take courses in physics and mathematics to bring their theory up-to-date. This creates a friendly rivalry between older and younger men, which gives the older men a chance to demonstrate that accumulated experience and ripened judgment help even in such matters as acquiring new knowledge.

The arrangement preserves a most desirable contact between education and industry as institutions and bears out the conclusion held by the writer for some time that among the ablest educators and practicing engineers are those who have had experience both in industry and in teaching. Also, the fact that university credit is given adds dignity and authority to the industrial training itself. The teaching experience gained by practical engineers serves to clarify and coördinate their own technical ideas in a way that would otherwise not develop.

The entire scheme has had a marked effect in raising the cultural standards of every one connected with it and has had much weight in combating the tendency to consider engineering as a trade instead of a profession.

It is to a considerable extent the answer to the problem so ardently pursued by the Society for the Promotion of Engineering Education of broadening and enriching the engineering curriculum without extending the span of the average undergraduate course beyond 4 years.

In closing I must pay my respects to Dean Sieg and C. S. Coler and their associates who have had the keen vision to combine and coördinate a natural growth or tendency with a competitive situation which concerns the student's time and life work and make from the two a practical contribution to American engineering education which is an outstanding accomplishment in that field.

E. B. Roberts: The authors point to the essential characteristics of engineering as a profession of creation and accomplishment. The necessity follows for the highest type of professional engineering education to nurture the desire and ability to create and accomplish. There is no concern here with preparing mediocre engineering graduates for the routine of design, testing, or application. There are grades of engineering and of engineering training, that are vocational, and there are grades that are professional. It is to the professional level of engineering that the authors of this paper have addressed themselves.

It is the relationship which engineering of creation and accomplishment bears as a step beyond scholarship and in the direction of the application of scholarship that makes the coöperative plan ideal in the graduate field. The period of apprenticeship to industry—the field of accomplishment and creation—proceeds in an atmosphere of university scholarship and research. The years of mental, physical, and social flexibility are used as they should be—for adjustment to life—but that adjustment proceeds in an atmosphere of scholarship and professional guidance.

The measure of success and recognition that has come to the plan rests upon the happy communion of vigorous teachers of character with able students. Problems of administration are few, and there is little mechanism of procedure. Unit courses there are, but these merely are the means of introduction of the students to their leaders and to the problems. The harmonious relationship of a superior student with a great leader, introduced through the mechanism of a course and maturing into the mutual study of an important scientific, mathematical, or engineering problem, is the aim. It does not seem so significant to us who are close to the program that educators who examine the plan find the Master's theses of our graduate students worthy of recognition as dissertations. The mind of the student is not much on the degree, or when he will receive it. Two-year and 3-year programs are not laid out. We prefer the lapse of three years for the Master's degree, and of 6 for the Doctor's. Continuous growth at a slow rate we value. Great capacity for sustained creative professional life, we believe, comes that way. It must be significant that the number of degrees granted is not affected by business and employment conditions. We shall continue to be satisfied with a dozen Master's and 2 or 3 Doctor's a year. The number of degrees granted is by no means a measure of the amount of work accomplished.

The faculty is balanced between the university and the industrial groups. The former are professional teachers of mathematics, physics, and economics. The writer is told by the university dean that there is a good deal of good natured competition in these faculties for assignment to Westinghouse classes. The industrial teachers of engineering subjects and leaders in the research are not professionally teachers, and but little effort has been made to develop in them a pedagogic viewpoint. They are selected because of their preëminence in their fields of science or engineering, and not because of degrees. While there are, as we look at the faculty roster, a considerable number of Ph.D.'s, several of those who have made the greatest contributions have no degrees except, perhaps, honorary doctorates. Each is left to his own way in developing his subject. Pedagogic tactics are unnecessary with the type of student involved. There are no undergraduate students in any of these classes, and no ordinary graduate students.

As we look back over 6 years of operation and progress of the plan, we see 3 significant values:

1. The development of an improved creative engineering ability among our younger engineers.
2. Continuing growth of the able few through those difficult years that should mark progress out of vocational engineering into professional engineering.
3. Important by-products in research and design, contributions to the literature of engineering, and in the sending out of a portion of those trained as engineering teachers or engineering leaders in other fields.
4. Mutual and favorable reaction on university faculty and design and research engineers, each developing a broader view through the contact.

The whole relation has proved a congenial and happy one. The entire effort of all concerned—university faculty, industrial faculty, students, and administrators—has been devoted to the creative side of the project. There have arisen no great differences of opinion or conflict of interests that have had to be arbitrated.

W. H. Timbie: In scheduling at the winter convention a session conducted by the committees on education and student Branches, the A.I.E.E. gives added evidence of the high value it puts upon the continued training of members of the profession, and certainly the 2 committees are to be congratulated in the choice of this paper. One of the greatest needs of engineering education at the present time is a closer coöperation between industry and the engineering colleges. The fact that very substantial and very definite benefits to the students, to the industrial organizations and to the engineering colleges result from such cooperation has been demonstrated again and again. But the combinations of different geographical situations, educational philosophies, and industrial policies are so varied, that each coöperative plan presents new possibilities and new advantages, all of which make it highly profitable from time to time to bring before the membership of the A.I.E.E. the details and the results of outstanding projects.

A study of these various projects might well form a starting point in the program of the committee on professional training of the Engineers' Council for Professional Development. This committee ought to find here a fertile field of ways and means in which we can take still greater advantage of the opportunities which already exist in our very midst.

Features which The Pitt-Westinghouse plan incorporates have been tried out either separately or in various combinations in several other localities.

The Bell System in New York City for years has been operating a plan whereby engineers associated with the system are able to complete graduate work at Columbia University in New York City, and the Polytechnic Institute in Brooklyn. The same arrangement exists between the General Electric Company and Union College at Schenectady. In both of these plans the young engineer gets his practical training in the industry but receives instruction in graduate studies at an engineering college, and is taught by members of the professional teaching staff of the college, rather than by members of the industrial organization.

The "Advanced Course" conducted by the General Electric Company at Schenectady (formerly called the Doherty Course) illustrates another variation. Here, while the young engineer is receiving his practical experience at the company's plant, he is instructed in advanced engineering theory by prominent members of the engineering staff of the company itself.

The coöperative course in electrical engineering, in which the General Electric Company and the Bell System coöperate with the Massachusetts Institute of Technology, offers still another variation. It utilizes this feature of instruction of students by prominent engineers of the industrial companies, but it does not limit this work to graduate study. In this coöperative arrangement the students spend alternate full terms at the Institute and at the plant of the coöperating company. While the students are with the company 2 classes a week are held, which are taught by outstanding engineers belonging to the industrial organization, but the subjects taught are not the particular subjects in which the engineers are specialists. Rather the subjects are integral parts of the course of study which make up the mathematical-physics backbone of the course in electrical engineering at the Institute. During those periods which the students spend at the Institute they are taught these subjects by members of the staff whose major interest is in teaching, but who, I venture to say, are just as good engineers as those employed in industry, but who have teaching as the major part of their work. Their outlook in general is not confined to one particular corner of the field of engineering. Thus the coöperative students take up successive vertebrae of their backbone course, first under an engineering teacher at the Institute and then under a teaching engineer at the plant of the coöperating company. The teaching engineer merely gives to the students at the plants the same subjects that they would have studied under an engineering teacher had they been at the Institute during that particular period. But these company engineers invariably bring to classrooms, viewpoints and sidelights differing from those with which members of the Institute staff endeavor to enrich the basic material of the same subjects. Such a dual approach to these fundamental theories affects a marked increase in the student's breadth of view, and in a decided whetting of his intellectual curiosity, 2 results which are prime objectives of all good engineering teaching.

Two other companies coöperating with the Institute on this plan have plants located in Boston. The students who receive their engineering practice with these companies, come to the Institute 2 evenings each week during their coöperative periods, and continue their studies under the instruction of members of the Institute staff. Thus, regardless of where the student is located, there is no break in his progress in the fundamental course of mathematical-physics which constitutes the backbone of his engineering curriculum. The success of this course has been marked and is evidence of the soundness of the underlying educational philosophy.

The variation in the method of utilizing the services of the outside engineer, whereby he teaches subjects which are unitary parts of the main stem of a student's course, rather than more or less isolated specialties, is due, in essence, to a different educational philosophy from that underlying the Pitt-Westinghouse plan, and is indicative of the wide variety of combinations and permutations that can be advantageously worked out in the coöperation between industry and technical colleges.

There still is another form of coöperation which has been in operation between the General Electric Company and the Massachusetts Institute of Technology since 1925. This plan represents yet another feature in educational philosophy and procedure. The General Electric Company for years has recruited its young engineers from among the graduates of engineering colleges located in all parts of the United States and Canada. To graduates who are qualified, the General Electric Company offers an opportunity to pursue graduate work at

the Massachusetts Institute of Technology leading to a Master's degree. The candidate makes application in the regular way to the Institute for graduate work. After he is accepted by the Institute the General Electric Company assigns him to the Lynn plant where classes are set up by the Institute in specified graduate subjects. The Institute sends regular members of its instructing staff twice a week to Lynn to conduct these classes. The young engineers carry on their work toward the Master's degree at one-third the usual rate at which they would progress were they attending the Institute full time. This continues for 3 terms, during which time the students have completed 1 term of graduate work. To those who have successfully completed the work, the General Electric Company grants a leave of absence for 1 term, which is spent in residence at the Institute. The young men are thus able to complete the work for the Master's degree in 2 years. Educational authorities agree that, in general, there are certain advantages to be gained when a student takes his undergraduate course at one engineering college, his postgraduate work at another, and at least part of his practical experience with a company outstanding in the comprehensiveness of its activities and in the high quality of its output. The last named course combines all 3 of these features. Business conditions have caused a temporary break in the operation of the course, but since the beginning of the course in 1925 40 men have received Master's degrees in Electrical Engineering, and 15 in Mechanical Engineering. From the Institute's viewpoint we are glad to state that these men constitute some of the best students enrolled in graduate courses in these departments. Their success is indicative of the effectiveness of the General Electric's recruiting organization, and of the appreciation which the higher type of engineering graduates have for the opportunities which this form of coöperation affords.

There is no doubt that in many localities in this country, conditions must exist which are favorable to setting up in several fields of engineering some form of coöperation between engineering schools and industry. In this connection there comes immediately to mind the automotive, chemical, and steel industries. We have seen the excellent pioneer work that has already been done. There is every indication that greatly increased opportunities will be opened up by the work of the committee on professional training of the Engineers Council for Professional Development. The reason that the Institute coöperates with the General Electric Company in the training of students who wish to enter the electrical manufacturing industry is because the great works of this company are in the vicinity of the Institute. It is our opinion that such coöperation should preferably be between engineering schools and industrial plants which are in the same vicinity. We also are proponents for definite arrangements whereby the students are placed in comprehensive companies and carry on their works employment with the same industry throughout the college course. Both of these features are characteristic of the Pitt-Westinghouse arrangement and in our opinion it is appropriately planned to meet the local situation.

Charles F. Scott: For the first time the committee on student Branches and the committee on education are functioning together. Two groups are concerned, the student before graduation and the student after graduation. These are recognized by the new Engineers' Council for Professional Development in which one division is concerned with engineering schools and another with professional training—the progress of the young graduate during the 4 or 5 years during which he is preparing through experience and study and all-'round development for full professional status. These groups will later on constitute the membership of the A.I.E.E. on which the standing and usefulness of the profession will rest.

These men are in the making; they are not yet experts. But our Institute functions largely through its technical committees—a score of groups of experts and super-experts. Each converses with itself on topics and in terms which may have little interest or meaning to the as yet uninitiated student and young engineer. Technical papers are apt to dominate our publications. Without lessening them, let us endorse the means now being taken in the special educational series to supply articles suited to our young members and urge that our joint committee on branches and education develop ELECTRICAL ENGINEERING as an aid in preparing these men for the New Deal and after.

Articles of this type will be welcomed by older members who appreciate the explanation of the fundamentals and the progress in fields other than their own.

C. C. Whipple: I have been giving quite some thought recently to the question of student membership in the A.I.E.E., especially as to how to make membership more attractive and more valuable to the students. It seems that about 70 per cent of the membership comes in through student membership. This being so, I believe that the Institute can well afford more specific attention to the student in its official publication, ELECTRICAL ENGINEERING. It has always fostered student activities in a very commendable fashion, but has omitted some possibilities in its official publication.

My suggestion is that the Institute devote at least 2 pages in ELECTRICAL ENGINEERING to matters of especial interest to students. Primarily the student is interested in having technical articles, which are up-to-date, but written more from the point of view of explaining to the student, and even to others, the matter at hand. My criticism, from the standpoint of the student only, is that the great majority of the articles in ELECTRICAL ENGINEERING are not written with this point of view. Rather the standpoint is that of the desire on the part of the author, or ones behind the author, to put on record their accomplishments, than to explain the subject carefully. Moreover, most of the articles or papers, are very technical, and involve previous knowledge which the student does not have. Please understand that this criticism is not necessarily one of Institute policy in general, but it does apply very directly to the student's standpoint.

These 2 or more pages could contain 1 or 2 short, rather complete technical articles, which might explain some new theory, new machine, instrument, method or procedure, or method of calculation, new or different standpoint on any of the many older theories. Every professor with a few years of experience has found in the course of his teaching that a certain method of explaining some theory, or the operation of some machine, or the solution of a problem, is especially effective in putting over the idea. These pages might include such of these articles as are of merit. But in all cases the idea behind the paper should be that of clear explanation. Furthermore, no one article should try to cover too much ground, either superficially or thoroughly. One idea fully covered would be of much greater value.

As a concrete example of the general type of article I have in mind, I can suggest reference to the *Electrician* published in London. This paper runs a "Student's Page" containing short technical articles, written with the idea of explaining something to the student, and I imagine in addition they are of considerable interest to others, who are engineers, but are not in their work dealing directly with the details of the matter at hand.

Also, I can suggest that throughout the Journal, or what is now ELECTRICAL ENGINEERING, there has appeared from time to time articles which could be included on these pages. I mention only a few: "A New Method of Calculating Circuits" by Kowenhoven and Pullen, November 1933, p. 776–9; together with the discussions; "Filters in Action" by Lane, December 1933, p. 813–16, although I think the explanation should be somewhat amplified and improved upon; "Alternating Current Analysis" by R. D. Mershon, January 1926, p. 43–5; and "Theory of the Autovalve Arrester," by J. Slepian, January 1926, p. 3–8. This last paper, together with several othet articles by Doctor Slepian could include a series of articles, perhaps modified or clarified. This list, taken at random from papers at hand, is not quite typical, but is to indicate possibilities only. If such articles were edited, and arranged on a page, headed in some suitable manner, to indicate that it was of special interest to students, I believe it would be an effective way of getting the students throughout the country more interested in ELECTRICAL ENGINEERING, and in the A.I.E.E. I believe also that students should be encouraged to write in discussion of these articles.

Included in this student's page, also might be, as suggested by Professor Weil, from Florida, and by Professor Seely, items with respect to student activities within the branches. I believe a record of the branch meetings of value, from the standpoint of record, and also other branches are anxious to know what is going on, and any event of especial interest might be written up in some detail. I believe that these matters should be secondary to the articles of technical interest.

I am very much in favor of having this "Student's Page" put in ELECTRICAL ENGINEERING rather than in a separate leaflet and by all means not mimeographed The students are a part of the A.I.E.E. just as much as any other type of member, and the "Student's Page" should therefore be an integral part of our official publication. It should not be separated therefrom, giving the student the idea of being an appendage.

Moreover, having it in ELECTRICAL ENGINEERING will create a greater desire for ELECTRICAL ENGINEERING on the part of students and they will thereby become acquainted with it, the men of the industry, and what the problems of electrical engineering are.

I am very much in favor of trying out this idea, for I believe it will grow, if properly done and allowed suitable scope. I suggest that the committee on education propose to the proper authority that this plan be carried out under its direction. My suggestion is that the material be edited by a group of engineering teachers, working in cooperation with the committee on education, the editors of ELECTRICAL ENGINEERING, and the papers committee.

Trolley Wire Lubrication Improved

Discussion of a paper by J. V. Lamson published in the November 1933 issue, p. 771–6, and presented for oral discussion at the transportation session of the winter convention, New York, N. Y., Jan. 23, 1934.

Reinier Beeuwkes: Some years ago consideration of the use of a solid graphite lubricant in place of the graphite grease lubricant was developed, while the electrification department of the Chicago, Milwaukee, St. Paul & Pacific Railroad was making investigation with respect to the possibility of definitely determining what the constituents of the more liquid lubricant should be to develop the most satisfactory results with respect to current collection and the securing of minimum wear of trolley wire. This investigation was being made at and about the time the recent business conditions were being severely felt and among other similar activities it became necessary to curtail this particular work. Mr. Lamson, who had been one of those engaged in this work on the railroad suggested, after his becoming connected with the University of Washington, that it might be possible for him to arrange to continue his investigation at the University. We of the railroad expressed the opinion that such work would be very valuable and that we would be glad to cooperate with him in every way possible. Mr. Lamson, as brought out in his paper, has been able to construct apparatus which, at least relatively, would in a short time enable correct conclusions to be drawn with respect to the advantages and disadvantages of the different lubricants considered. On basis of the early results Mr. Lamson secured, the railroad decided to make extensive trial of the solid graphite form of lubrication. Two methods of using solid lubricant are being tried out on the railroad:

1. In one method a soft mixture containing graphite and other ingredients furnished by one of the graphite manufacturers is packed around a reinforcing screen which extends across the hollow part of the pan between the copper contact strips, the screen being held in place by clamping it down under the contact strips. When the paste has been packed around the screen it is baked and is then ready for use. Care must be taken, of course, to see that no part of the lubricant extends above the copper strips.

2. The second method we are trying consists in the use of an auxiliary lubricating block, also formed of the baked paste mounted adjacent to the regular collecting pan as referred to in method No. 1.

We have been running these 2 arrangements on the Coast division of the railroad for a year or more, and during the late summer also extended their use to the Rocky Mountain division. There have been complaints by the mechanical department that the graphite lubricant results in considerable grooving of the contact strips. Recent grooving, at least on the Rocky Mountain division, has occurred with both forms of lubricant, and has been due to heavy frost conditions, in some cases not enough care having been taken to see that both pantographs were raised, as is called for by our instructions when frost conditions are encountered.

It may be that the question of the amount of current to be collected, that is, the current density, has an influence on the relative advantages of the soft and solid lubricant, respectively; or, other conditions may affect the situation. Therefore, I should have liked very much to have seen laboratory tests carried on a sufficient length of time to enable the answer to some of these questions to be determined, or at least indicated. Such further tests, however, we have not been able to arrange for, and we are still depending on actual operation to determine finally the relative advantages of the solid and soft lubricant. We think the solid graphite has important advantages, and would wish to determine definitely that there are still more important disadvantages before we gave up considering its use. On this basis, the results so far obtained have justified continuing with the tentative use of the solid lubricant.

Harry Brown: Mr. Lamson's paper on trolley wire lubrication is timely; it is indicative of the increasing amount of interest in, and of the amount of study and experiment being devoted by many engineers to this subject.

It is generally conceded today that lubrication is necessary for the proper operation of a sliding collector on a contact wire, whether for high speed heavy electric traction service, or for the lighter traction services, such as is represented by the modern trolley bus. There are 2 major prevailing opinions as to the best method of applying the lubricant. One method, the oldest and perhaps the easiest method, is to lubricate the collector. Nearly all sliding collecting devices are designed for lubrication of this kind, as mentioned by Mr. Schaake in his paper on pantograph design. Where runs are short, and in busy sections like yards and terminals, this method may be entirely satisfactory, if persisted in, since in time the contact system becomes more or less covered with lubricant transferred from the collecting device. The second method, which I am inclined to believe is the better one, is to apply a lubricant of some kind directly to the wire itself, by some means other than the pantograph, often enough to replace that amount removed by friction or by the action of the elements.

The New Haven Railroad has for years been lubricating the pantographs on its electric rolling equipment, in accordance with the first method. During the past year we have been making extensive experiments with lubrication applied directly to the wire itself, on certain parts of the overhead system at a distance from the terminals, keeping a record of the wire wear. Definite quantitative data on relative wear will be obtained, it is hoped, by the time these tests are concluded. Lubrication of the pantograph is also being continued, as in the past. There are many kinds of lubricants on the market today designed for this purpose, ranging from soft grease to be smeared on the wire, to harder putty-like graphite compounds in the form of sticks to be rubbed on the wire, and also including compounds containing finely divided graphite in solution in a volatile vehicle which is quick drying and is sprayed on the wire. No data is yet available as to the superiority of any of these various kinds of lubricants. The stick graphite, is perhaps, the method most easily applied to our overhead system.

The exact nature of the lubricant referred to in Mr. Lamson's paper is not given. One serious objection to the method used is the added weight to the pantograph shoe, at the very part, which Mr. Pickens in his paper shows should be of minimum weight and inertia for high speed operation. The method, however, may be perfectly satisfactory for slower speeds.

W. H. Bassett, Jr.: Mr. Lamson is to be congratulated on his careful study of a very important transportation problem. Especially interesting are his remarks regarding the polishing of the surface of a trolley wire or a copper bus bar wheel ring after extensive tests with solid lubricants. It has been the experience of the Anaconda Wire & Cable Company that the burnishing of the wire and pantograph collecting strip to a commutator glaze results thereafter in minimum wear of both electrical and mechanical origin on the contact surfaces.

In 1928 we built at the Ansonia laboratory, of the Anaconda company a test machine designed to test various kinds of trolley wire and pantograph material. It was hoped that by running these tests, we would be able to evaluate resistance to wear of various pantograph materials and

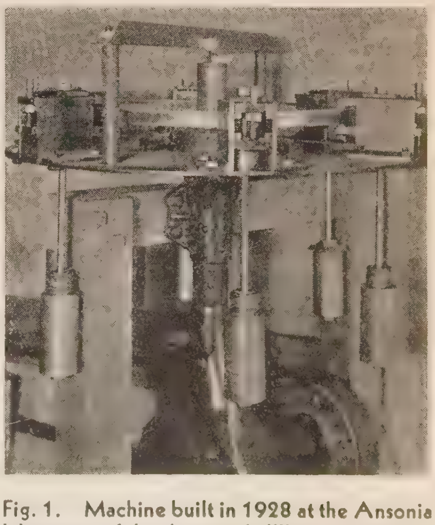


Fig. 1. Machine built in 1928 at the Ansonia laboratory of the Anaconda Wire & Cable Co. for testing trolley wire and pantograph material

of the amount of wear these alloys would cause on the copper and copper alloy trolley wires. Figure 1 shows the general arrangement of this testing machine.

A $^5/_8$-in. thick copper disk was mounted on a vertical axle which was rotated so that the periphery of the disk traveled at a speed varying from 10 to 30 mph. The wearing surfaces consisted of $^3/_{16}$-in. thick hot rolled low carbon steel rings which were riveted to the top and bottom surface of the $^5/_8$-in. thick copper disk. In order to prevent overheating of the steel rings, the copper disk was cooled by means of a water chamber which kept the temperature of the disk from rising above a maximum of 212 deg F.

The 3/0 B&S gauge trolley wire samples were placed against the top and bottom steel rings at 6 equidistant points around the circumference of the wheel. The pressure of the trolley wire samples against the wearing ring was varied by means of levers and dead weights. It was found necessary to make the levers carrying the specimens out of copper and mount a water chamber on same in order to keep the temperature of the trolley wire below 212 deg F. The 3/0 B&S trolley wire test pieces were cut $2^1/_4$ in. long. A slot $^1/_4$ in. wide and $^1/_8$ in. deep was cut in the middle so that a countersunk screw could be used in attaching the sample to the lever arm.

After preliminary trials, we standardized on the test procedure as follows:

Speed.............	10.2	miles per hour
Load..............	2.5	lb per lineal inch
Length of run......	500	miles of rubbing contact

No lubrication was used in these tests. The trolley wire samples had the standard hard drawn mill finish which they receive in normal manufacturing operations. The steel wear plates were machined smooth and finished with No. 00 emery cloth.

It was found that the rate of wear of the trolley wire samples increased quite rapidly during the first 10 miles of the run after which the rate of wear dropped off again reaching an approximate constant value at 40 miles and changing very little from that point up to the end of the 500-mile run. The copper was worn away from 3 to 4 times as fast as the bronze trolley wires.

In later tests, a graphitic steel known as "gunite" was used. In addition to the ferrous rings, we also experimented with nonferrous wear rings having a relatively high copper content. Where the samples were subjected only to mechanical wear, it was found that the amount of wear on the trolley wire was entirely dependent on how soon the surfaces became burnished or glazed. As soon as the surfaces obtained the high polish, the test could be continued indefinitely without any appreciable change in the trolley wire samples or the wear rings.

When the samples were subjected to both mechanical and electrical wear, it was found that the arcing and pitting of the surface affected the rapidity with which the surfaces became glazed. A current of approximately 70 amp was used to produce the effect of electrical wear.

All of the tests seem to indicate the importance of using highly polished pantograph wearing surfaces in order that the pantograph as well as the trolley wire might become burnished or glazed as rapidly as possible so as to reduce the amount of wear to a minimum. As may be noted, no lubricants were used in these tests, and it may be that the use of solid lubricants by Mr. Lamson will materially hasten the formation of the so-called commutator glaze on the wearing surfaces of the current collectors.

Investigation of Rail Impedances

Discussion of a paper by Howard M. Trueblood and George Wascheck published in the December 1933 issue, p. 898–907, and presented for oral discussion at the transportation session of the winter convention, New York, N. Y., Jan. 23, 1934.

K. L. Maurer and E. D. Sunde: The method mentioned in this paper of substituting for a steel rail an equivalent round conductor of unit permeability and zero internal reactance was utilized in some measurements made in 1931 of the electrical constants of several rail samples of dimensions differing somewhat from those described in the paper. These tests were made jointly by the Pennsylvania Railroad and the American Telephone and Telegraph Company in connection with studies relating to inductive coordination of communication and railway electrification facilities.

The tests covered rail weights of 100, 130, 131, and 152 lb per yard, all being standard Pennsylvania Railroad sections. For all but the 100-lb size, 2 samples of each size were tested, new rails being used in all cases. The 100- and 130-lb samples although differing somewhat as to dimensions and chemical composition from the samples of corresponding sizes described in the paper, gave average values of a-c resistance and total reactance that are in practical agreement with results given in the paper. Dimensions of the 131-lb rail, which is an A.R.E.A. standard, and of the 152-lb rail are given in Fig. 2 in which the experimental results are plotted. The measurements were made at 25 and 60 cycles and for rail currents up to 700 amp. The results are shown in a form that enables extension of the values at the above 2 frequencies to other frequencies over a limited range and with precision sufficient for ordinary engineering purposes. The justification for this use of the data is given in the following paragraphs.

The testing arrangement used was essentially similar to that shown in Fig. 1 of the paper except that the loop supplying current to the rail was in a horizontal plane and the loop for measuring the impedance drop in the rail, also in a horizontal plane, was about 30 ft wide and 30 ft long. With a given rail energized at different currents I, the voltage V appearing in the voltage measuring loop connected to the rail at 2 points 30 ft apart was measured for each value of I. Upon completion of these measurements, the rail was removed and a $^5/_8$-in. copper pipe of the same length as the rail was substituted in its place, parallel to which

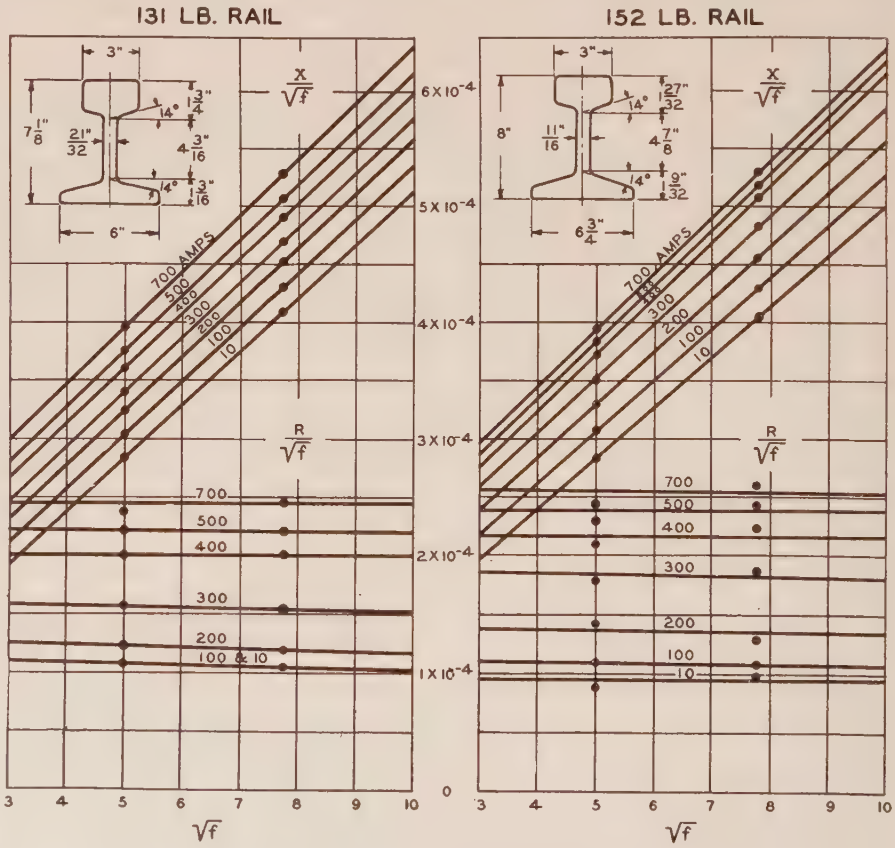


Fig. 2. $R/\sqrt{f}$ and $X/\sqrt{f}$ as functions of $\sqrt{f}$ for various rail currents

R and X are resistive and reactive components of voltage measured in test loop per ampere rail current; f = frequency in cycles per second. Length of test section 30 ft. Temperature of rails during test 102 deg F for 131-lb, and 93 deg F for 152-lb rail. D-c resistance of test section 243 × 10^{-6} ohm for 131-lb rail and 204 × 10^{-6} ohm for 152-lb rail. Rail perimeters 28 in. and $30^5/_8$ in. for 131- and 152-lb rails, respectively

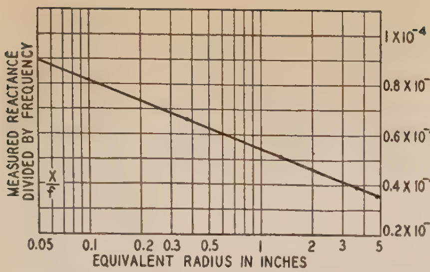


Fig. 3. Radius of round conductor equivalent of rail as function of 1/f times the reactive component of the loop voltage per ampere

exploring wires, also 30 ft long, were arranged at separations ranging from approximately 0.4 to 5 in. With the exception of the rail portion, the primary or current loop, and secondary or voltage measuring loop, were left unchanged. With a current I_1 in the primary loop, the induced voltage V_1 was measured in the secondary loop closed by each of the above wires in turn. The ratio V_1/I_1 was then plotted against the separation of the exploring wires. The real components of the ratios V/I for the rail are the a-c resistance values corresponding to currents I for the test length; the reactance component of V/I corresponds to some equivalent radius which is found by taking the separation in the plot of V_1/I_1 to which this reactance component corresponds. Since the primary and secondary loops were exactly the same for the 2 sets of tests the results are independent of their size and arrangement; except that the primary loop must be made large enough so that the distribution of current in the rail is unaffected by the return current, and the secondary loop must be large enough so that the position of the pipe with respect to the centroid of the rail sample is not critical.

On the accompanying Fig. 2, giving the average results of 2 samples each of 131- and 152-pound rails, the impedance components measured in the secondary loop divided by $\sqrt{f}$ are plotted against $\sqrt{f}$, and straight lines are drawn through the points. This linear extension of the results is theoretically justified, since for a conductor having a high permeability and a large perimeter, such as a rail, the internal resistance and reactance are nearly proportional to $\sqrt{f}$ when the frequency is not too small. The reactive loop voltage includes 2 components, one of which (the internal reactance) is nearly proportional to $\sqrt{f}$ and the other (the external reactance) proportional to f. Hence, the reactive component divided by $\sqrt{f}$ is approximately a straight inclined line when plotted against $\sqrt{f}$. This may be verified by plotting the total reactances given on Fig. 14 of the paper in this manner.

With the pipe substituted for the rail, as described, the induced voltage per ampere in the secondary loop divided by the frequency was the same at 25 and 60 cycles, as, of course, should be the case. On Fig. 3 this quantity is plotted against the separation at which it was measured. This separation is equivalent to the radius of a round conductor of zero internal reactance located coaxially with the pipe.

In order to calculate the total impedance of the rail its equivalent radius at the desired frequency and rail current is obtained as follows: The value of $X/\sqrt{f}$ in Fig. 2 s divided by $\sqrt{f}$, and the equivalent radius corresponding to the value of X/f thus obtained is taken from Fig. 3. The resistance of the continuous rail per mile is obtained by multiplying the values of R obtained from Fig. 2 by the numerical factor 176. With the resistance and equivalent radius known, the impedance is readily calculated as for ordinary conductors except that the internal reactance of the equivalent conductor is to be taken as zero. In calculating mutual impedances the equivalent conductors, of course, should not be used for separations so small that the proximity effect is important and in no case for separations less than about the diameter of the "external reactance circle" described in the paper, which, as there mentioned, can for practical purposes be taken as the rail perimeter divided by π.

Harry Brown: Trueblood and Wascheck in their investigation of rail impedances have contributed a valuable addition to the meager bibliography existing on this subject. The graphical and tabular data presented are concise enough to be included in all forthcoming editions of the several reference handbooks dealing with electric railway data. In connection with the investigation of bonded joints, it is to be noted that the bonds used are somewhat heavier than would ordinarily be used in operating practice on a-c electrifications, but the difference is without doubt a very small portion of the total impedance. It would have been of interest to have included data on the impedance of unbonded joints, since in actual operating practice there is, no doubt, a large amount of current carried through the splice bars themselves, through the areas in close contact with the rail, kept bright by the vibration and rubbing action of the various parts under traffic conditions. This, however, may be too much of a variable, under varying conditions of temperature and moisture, to be tabulated accurately, but would seem to warrant some careful study.

It would be of interest also to have information on the impedance values when 2 similar rails are in parallel at gauge distance apart, a condition usually found in propulsion current returns, as well as impedance of a similar parallel rail circuit, with rails in series as found in signal current circuits. It is assumed that the presence of the earth as a parallel conductor, is a minor factor in such impedance investigations.

Pantograph Trolleys I—Design Features

Discussion of a paper by W. Schaake published in the January 1934 issue, p. 182–9, and presented for oral discussion at the transportation session of the winter convention, New York, N. Y., Jan. 23, 1934.

Harry Brown: In his paper, Mr. Schaake has presented, for the first time, the actual design details, relative advantages and disadvantages, and limitation of the various types of pantograph current collectors now in use. One change in original design not mentioned in his paper, which was made to the New Haven pantographs, has been the cambering or bowing upward of the original flat shoe. This was done for 2 main reasons:

1. To reduce the tendency of the pantograph, as it swayed transversely to the track, from hooking into crossover or turnout wires with its high end (the radius of the camber being made approximately equal to the radius of transverse oscillation) thus allowing no part of the pantograph to be higher than the point of contact with the wire, regardless of amount of swaying.
2. To reduce the possibility of a worn pantograph from becoming concave or "broken backed," and having its ends higher than the center, from hooking into, or striking steady wires, and crossover or turnout contact wires. Our experience with this bow shaped shoe has been very satisfactory. As Mr. Schaake states, except for minor improvements, in bearings and joints, and also in insulation, the pantograph now in use on the New Haven has been changed but little from its original design.

The use of side guards shown in Fig. 9, and applied, I believe, to the Virginian, the Milwaukee, and the Cleveland Union Terminal pantographs, never has been quite clear to me. I cannot see how a shoe that has slipped off a contact wire ever can get back again under the wire, even with guards, and the pantograph will necessarily foul the first obstruction encountered in the overhead contact system, even with guards. For the additional weight and inertia, the advantages of this feature should be more readily apparent.

Pantograph Trolleys II—Operating Features

Discussion of a paper by B. M. Pickens published in the January 1934 issue, p. 190–4, and presented for oral discussion at the transportation session of the winter convention, New York, N. Y., Jan. 23, 1934.

Harry Brown: In his very admirable paper Mr. Pickens shows very clearly the desirability of limiting the normal contact wire height to the lowest value consistent with operating safety. Since other economic factors in contact system design also influence this feature, it might not be inappropriate at this time, with over a quarter of a century of operating experience to draw upon, to urge the adoption of a standard contact wire height. One of the committees of the Electrical Section of the American Railway Association indeed is working on this very problem, as it is closely associated with the subject of standard clearances. The consensus of opinion of engineers familiar with the design and operation of contact systems, seems to favor the adoption of a standard nominal height of 22 ft with standard rolling equipment of present day dimensions.

Another conclusion clearly indicated by Mr. Pickens is the importance of coördinating the contact system design and the design of the pantograph collector. There has been without doubt, too little done along these lines in some of the earlier installations, and there are many features in contact system and pantograph designs that are still capable of improvement, in spite of changes and improvements that already have been made. His analysis of

high speed pantograph operation on 300-ft catenary spans, again points out the fact that this length of span, while almost universally used in this country as a standard, seems to be a little too great for satisfactory high speed operation, as well as for certain features of the contact system design itself, which limitations I have previously pointed out (see A.I.E.E. TRANS., 1925). In this connection, it was this limitation which prompted the adoption of the so-called compound catenary by the New Haven railroad, when it extended its original electrification from Stamford to New Haven, Conn., in 1912. On this section, although the supporting structures are 300 ft apart, nominally, the effective span length for the contact catenary is only $^1/_2$ of that distance, or 150 ft. Thus the temperature variations in the catenary are only $^1/_4$ of what they would have been for a 300-ft span. With the adoption of speeds appreciably higher than those now in use, it may be necessary to resort to flexible or "lifting hangers" especially at or near the supporting structures, to increase the flexibility of the line, although in the past many disadvantages have discouraged their general use. The use of an auxiliary pantograph carrying the collector shoe also becomes more apparent, with higher speeds. In the past, terminal clearances have limited the use of this feature on many installations where its desirability has been recognized.

The 3-Phase Electric Arc Furnace

Samuel Arnold, 3rd, December 1933 issue, p. 839–43.

Transformers for Electric Furnaces

H. O. Stephens and L. S. Schell, Jr., December 1933 issue, p. 822–5.

Electrodes—Carbon and Graphite

Frank J. Vosburgh, December 1933 issue, p. 844–8.

Electrical Equipment for Induction Furnaces

C. C. Levy, January 1934 issue, p. 43–8.

Rocking Indirect Arc Electric Furnaces

E. L. Crosby, January 1934 issue, p. 132–8.

High Frequency Induction Furnaces

C. A. Adams, J. C. Hodge, and M. H. MacKusick, January 1934 issue, p. 194–205.

Cast Iron and Its Production

M. V. Healey, January 1934 issue, p. 120–3.

Discussion of a group of papers presented for oral discussion at the session on electric furnaces of the winter convention, New York, N. Y., Jan. 23, 1934.

N. R. Stansel: A more complete title for this symposium is "Electric Furnaces for Melting Metals and Alloys." An important topic in the metal industry is "improvement in methods of melting," and this symposium on electric furnaces is a contribution to that general subject as well as a presentation to electrical engineers of the present status of the electrical industry in a particular field of the utilization of electric energy.

Samuel Arnold's paper contains many interesting points for discussion. Some of these are noted in the following paragraphs.

Furnace Ratings. The adoption of a standard method of rating arc furnaces would be of much benefit to the metal industry. Along with this is the pressing need for the standardization of 3-phase arc furnace voltages. The necessity of using a given size of furnace shell for a considerable range of production and for more than one class of melting service may prevent the standardization of sizes of transformers for different sizes of furnace shells, but the flexibility of the variable ratio transformer described in the paper by Stephens and Schell appears to make it practicable to standardize furnace voltages.

Thermal Insulation of Arc Furnaces. The paper states that the major problem of this insulation is power limitation.

Large Furnaces. A feature of electrical apparatus is convenient and efficient divisibility. During the past few years a number of comparatively small 3-phase arc furnaces have been installed as supplementary units. The small furnace is supplied by the electrical equipment of the companion large furnace, but not, however, simultaneously. The variable ratio transformer makes this procedure easily possible. There is often a marked advantage in having a small furnace to meet low production conditions, special orders, etc.

The secondary bus of a 3-phase arc furnace is an important element of the installation. The following recent papers deal with this subject:

ELECTROMAGNETIC FORCES ON CONDUCTORS WITH BENDS, SHORT LENGTHS, AND CROSS OVERS, C. W. Frick. *G. E. Review*, May 1933.

BOLTING OF BUS BAR JOINTS, E. B. Shand and C. E. Valentine. *Elec. Journal*, Sept. 1933.

ENGINEERING CALCULATIONS OF INDUCTANCE AND REACTANCE OF RECTANGULAR BAR CONDUCTORS, O. R. Schurig. *G. E. Review*, May 1933.

CALCULATION OF INDUCTANCE AND CURRENT DISTRIBUTION IN LOW VOLTAGE CONNECTIONS TO ELECTRIC FURNACES, C. C. Levy. A.I.E.E. TRANS., Dec. 1932.

The increasing use of the single phase arc furnace in the iron foundry industry is a phase of load building that is unusually attractive to the central station industry. E. L. Crosby's paper, in addition to describing the single phase furnace, contributes much useful information on a new engineering material, electric gray iron.

The paper by M. V. Healey continues the discussion of electric gray iron in a way that should be of much interest to electrical engineers. Gray iron is a material of widespread use, and the utilization of the electric furnace in gray iron foundries is thus attractive to every central station.

The essential feature in the production of this new gray iron, after correct analysis, is a temperature-time relation for the molten metal, i. e., a heat treatment process applied to the molten metal, before pouring. The general method for the production of this new engineering material is electric furnace melting; first, because of the temperature required, and second, for economic reasons which pertain to the utilization of scrap and to production schedules. Hence, the term "electric gray iron" which is coming into use is well suited to this new material and parallels the long established term "electric steel."

It should be noted that Table I of the paper by Mr. Healey is a comparison of the local costs of unlike products. Industrial electric heating is a branch of product engineering, that is, the criterion of its use is the product. Hence, in all cases the character of the product is the basis of the economics of the method rather than a comparison of unlike products as in the case cited above.

Attention is invited to the recent publication entitled "A Symposium on Cast Iron" by The American Foundrymen's Association and The American Society for Testing Materials. Also many important articles on the production of gray iron in the electric furnace have appeared in the technical press during the past year.

One feature that distinguishes the arc furnace from the induction furnace is the electrodes. Improvements in electrodes have kept pace with the developments of arc furnaces and of the auxiliary apparatus for this class of equipment. The paper by Frank J. Vosburgh brings to engineers essential information on this important element in arc furnace operation.

The paper by Prof. Adams, Dr. Hodge, and Mr. MacKusick includes design features, metallurgical considerations, and operating characteristics of the coreless induction furnace. It is thought the term "coreless induction furnace" is better than the term "high frequency induction furnace" often used, and used as the title of this paper. The term "high frequency" is indefinite, and particularly so now that so many frequencies above 60 cycles are in use for various purposes.

The continuous growth in the use of alloy steels is noteworthy and of particular interest to the electrical industry because of the extent of the use of the electric furnace for the manufacture of these steels. A particular use of the induction furnace in stain-

less steel production is described in a paper entitled "Stainless Steel Production—Equipment and Manufacture" by E. C. Smith, with discussions by V. B. Browne and Walter Mathesius published in *The 1932 Year Book* of the American Iron and Steel Institute.

The special features of the electrical equipment for coreless induction furnaces are described in the paper by C. C. Levy. Both this paper and the preceding paper refer to the inductor generator. Further information regarding the design of this type of generator is given in the first part of the paper entitled "Inductor Alternators for Signaling Purposes" by F. W. Merrill, which appeared in the January 1934 issue of ELECTRICAL ENGINEERING, p. 78.

In conclusion, a paragraph from the annual report of the A.I.E.E. committee on electrochemistry and electrometallurgy for the years 1929–30 (ELEC. ENGG., v. 50, 1931, p. 570) seems of sufficient significance to warrant repeating it here. After noting the magnitude of the electrochemical and electrometallurgical industries of the United States this report continues:

> "Quantities and percentages such as these would seem to warrant the liveliest interest on the part of men having electrical training, particularly the younger men who find themselves faced with limited opportunities for advancement in those more standardized fields of the electrical art involving the design and manufacture of apparatus for the production and distribution of electric energy. The development of new materials or processes based upon the utilization of this power is a field requiring talent of a high order and one which it seems should be very attractive to men of electrical training who can and will superpose on an electrical background a knowledge of the fundamentals of physical chemistry."

C. L. Dudley: The metallurgist is interested in quality of product and its control while the foundryman is interested in producing to the limit of his mould capacity at the minimum cost for materials and energy.

It is my understanding that the melting efficiency (pounds per kilowatthour) is not directly proportional to the increase in kilowatt rating of the furnace, but increases at a greater rate. This naturally would tend toward the foundryman's demand for a larger unit.

These installations are not always of such size as to make supply source voltages of 13 kv or higher an economical proposition for either the customer or the utility company. Loads on a 4-kv distribution system that require starting currents of the order of 50 or 100 amp per phase begin to be serious problems because of the voltage disturbances caused to other customers.

In the direct arc type of furnace the violent fluctuations of current inherent during the melting down process are even more serious.

We are therefore faced with 2 problems:

1. The initial starting condition which may last several minutes.
2. The normal operating condition which may last an hour or more.

It is gratifying to note in Mr. Crosby's paper (p. 135) that, "If it is desirable to hold the fluctuation or current surge to lower values than these (2 or $2^1/_2$ times normal) this may be readily accomplished by inserting an additional reactor in circuit when starting a cold furnace, very simple switching equipment being provided for short-circuiting this reactor after the arc has been in operation for a few minutes." This partially at least solves one problem and gives our regulators a chance to pick up the load.

The only general answer to the direct arc furnace seems to be a motor generator set which, of course, is very expensive.

Apparently the indirect arc furnace as described by Mr. Crosby overcomes some of the difficulties of this second class. This is probably especially true for ferrous metal uses though in nonferrous production, with which the Public Service (N. J.) Electric & Gas Company has had considerable experience, it leaves a lot to be desired.

There is, however, one serious objection to the indirect arc type of furnace as now constructed. It is a single-phase device and as such produces a bad line load unbalance in the case of the consumer who has only one unit.

This unbalance does 2 things: first, it ties up considerable valuable circuit capacity from which the utility cannot obtain any return; second, it causes polyphase rotating apparatus on other customers' services to try to rectify the unbalanced conditions and thereby penalize them for no fault of their own.

Most of these furnace installations obtain energy at off-peak rates and it would seem only fair that the single-phase user should be penalized in some way, perhaps in rate structure—which is already complicated enough—or in use of motor generator set, phase-balancer set, or in the installation of 2 or 3 furnaces which can be balanced on the circuit for normal operation. Possibly the indirect arc furnace can be redesigned as a polyphase device.

Mr. Crosby is to be congratulated for the inclusion of the oscillograms in his paper. I am sure the operating engineer would appreciate more data of this nature.

The 3-Phase Electric Arc Furnace

Discussion of a paper by Samuel Arnold, 3rd, published in the December 1933 issue, p. 839–43, and presented for oral discussion at the electric furnace session of the winter convention, New York, N. Y., Jan. 23, 1934.

Frank W. Brooke: Mr. Arnold has brought out 2 phases of electric arc furnace practice that I would like to discuss.

First: Thermal Insulation. This has been tried. In the first experience I had some 18 years ago, a $2^1/_2$-in. lining of "Sil-o-cel" was used on a 6-ton melting furnace and the lining after a few heats broke down. Since then more conservative insulation has been used. There is a balance between the permissible heat insulation and the cost of refractories, particularly in basic operation.

It is difficult to compare the open-hearth with the electric furnace under this heading. The open-hearth has much greater areas of heat surfaces. There are the furnace chamber, ports, checkers, flues, etc. Parts of these are at [illegible]tures that permit insulation. A [illegible] difference between heat los[illegible] hand

the electric furnace is brought about by the air infiltration. The electric furnace from the very beginning was encased in a steel shell. Its design permitted this and this great advantage has not been sufficiently realized.

Second: Furnace Rating. Let us confess that we furnace builders have been more responsible for this confusion than anyone else. As Mr. Arnold points out there is no one cure-all; however, we can eliminate some of this confusion by cutting out such items as theoretical bath contour referred to by Mr. Arnold, and extravagant overload figures. I would like to suggest a full discussion of the problem by the 3 manufacturers of direct arc melting furnaces along the following lines:

(*a*) *Holding Capacity.* Arrive at a standard of furnace shell diameters and eliminate nominal capacities and the *XYZ* sizes. Establish a relation between these diameters and some vertical dimension so as to define the scrap holding capacity. Define a recommended lining thickness to conform with brick standards. This will entail sacrifices on the part of each manufacturer, but similar sacrifices have been made in nearly every other industry and I can assure the full coöperation of my own company along this endeavor.

(*b*) *Electrical Capacity.* Agree upon an understanding of transformer capacity, such as the A.I.E.E. temperature rating based on an assumed full load for 24 hours. Eliminate any time cycle rating. Establish a "name plate" that gives the necessary information to the furnace user. Makers of electric furnace transformers have in the past been anxious to help in such a standardization and will, I am sure, do all in their power to arrive at a fair result. Let us cut out for instance all "in between" kilovoltampere capacities using as a suggestion such figures as:

500	1250	2000	4000
750	1500	2500	5000
1000	1750	3000	7500 etc.

(*c*) Establish a recommended set of combinations of holding capacities and electrical capacities for typical conditions.

It will still require an expert furnace engineer to study each application, but he will have definite factors to work from and the prospective user will be in a much better position to know what he is getting and to know what the operator should produce.

C. C. Levy: After reading Mr. Arnold's excellent paper on the subject of the 3-phase electric arc furnace, particularly as used in the production of ferrous materials, it occurred to me that while excellent treatment of the various types of ratings and the reasons for them had been given in the paper, no conclusion as to the standardized practice had been reached.

According to the paper, a furnace rating may be any of the following:

1. The nominal rating based upon the dimensions of the bowl and meaning the tons of molten metal charge when the furnace is first installed.
2. The tons per hour production which is explicit only when associated with a certain product and is explicit only for acid work on account of the variable time of refining.
3. The diameter of the shell.
4. The transformer capacity.

It appears that all of these features are necessary to the complete understanding of a furnace rating from one point of view or another. Unfortunately the number of these is too great to be convenient in describing a furnace except in a formal specification. As a suggestion for ordinary descriptive use we would like to ask Mr. Arnold whether the diameter of the shell

and the nominal charge rating followed by a statement as to the maximum net tons which can be charged would not be a satisfactory method of describing a furnace rating. Any operator desiring to know his tonnage could readily work this out from a knowledge of the process, whether it were acid or basic, and the type of product he was melting.

Another feature of interest on which we should appreciate additional information from Mr. Arnold is the subject of furnace insulation. This subject is mentioned rather briefly and we feel sure that a discussion of the problem, and any experimental work that has been done together with results obtained would be of great interest. The problem appears to be that when insulation is used the rate of energy input must conform to the rate of heat dissipation as otherwise refractory failures would occur. Experimental difficulties in determining the rate of heat dissipation are doubtless the cause for failure to reach a successful operating condition. Another difficulty seems to me to lie in the fact that for melting-down the rate of energy input usually is made high and it is not at all likely that this rate of input would conform to a desirable rate for an insulated furnace.

Transformers for Electric Furnaces

Discussion of a paper by H. O. Stephens and L. S. Schell, Jr., published in the December 1933 issue, p. 822–5, and presented for oral discussion at the electric furnace session of the winter convention, New York, N. Y., Jan. 23, 1934.

S. S. Cook: It seems to me that the paper by Stephens and Schell stresses too strongly the desirability of providing conservators or expansion tanks for furnace transformers. Their use may involve difficult tank construction and furthermore they may not be as necessary as might at first appear.

In order that the conservator may function properly the tank, including the joint between the low voltage leads and the cover, must be oil tight. If the low voltage current is small enough to permit the use of ordinary oil tight bushings, an oil tight joint between bushings and cover easily is obtained. Such bushings are, however, not good for more than about 4,000 amp each and there is not cover space for many of these bushings in parallel—particularly on a 3-phase unit. For heavy current units, therefore, many bus bar leads are essential, which, because of space limitations and to minimize lead reactance, must be spaced close together. Making these bars oil tight under pressure where they come through the cover is difficult and expensive. It could be done, and estimates have been prepared covering furnace transformers with oil conservators and with "inertaire" protection, which I consider preferable. However, the additional expense and risk of leaks involved does not seem justified.

The paper states that several furnace transformers with conservators have been built, but there are none indicated in the illustrations which all show heavy current units with bus bar low voltage leads. I should like to ask if those built with conservators were large units for furnace operation, and what low voltage currents were involved?

I do not believe there is any great need for a conservator on the usual furnace transformer because:

1. Furnace transformers are usually in a separate room where the air is reasonably free from dust and it is not difficult to provide sufficient packing around the low voltage leads and other cover openings to prevent the entrance of dust and dirt into the tank.

2. These transformers are of the water cooled type with reasonably high temperature gradients between copper and oil; hence the oil rise is not great (about 25 deg C for a 40-deg unit). Therefore, the variation in oil volume with variation in load, and consequently the breathing, is not as great as in an ordinary power transformer. With a very small amount of breathing there is not much likelihood of moisture entering the tank. This is particularly true since these units are invariably of the indoor type and are installed in a dry place of reasonably uniform temperature.

3. The temperature of the oil in a furnace transformer is low, probably never more than 60 deg C; at this temperature sludging is very slow even when in contact with air.

For these reasons it seems that the conservator is not needed and that it would not materially improve the life or performance of the unit. If provision for breathing is required, a good chloride breather is all that is necessary.

The scheme of paralleling the high voltage winding as shown in Fig. 1 of the article, so that operation on the taps will affect the paralleled low voltage coils equally, is a good one unless the high voltage current is too low to permit many subdivisions.

A somewhat simpler modification that gives the same effect, is to design for parallel connection only the parts of the winding containing the taps, having one part in each high voltage group. The remainder of the winding can be designed for series connection throughout and connected in series with the tapped circuit. This improves the space factor of the winding and lessens the number of leads that must be connected to terminals or tap changer.

It is well known that in paralleled transformer coils the load divides inversely as the impedances, other things being equal. One should not be misled by the fact that the difference in the impedances given in the paper for paralleled low voltage coils at the top and bottom of the stack of a core type transformer with interleaved windings, is only 0.14 per cent. That 0.14 per cent is 0.14 in 100; but expressed in terms of the impedance of the shortest circuit, it is 3.6 per cent. This means that the current in the top coil would be 3.6 per cent more and the loss about $7^1/_2$ per cent more than the corresponding values in the bottom coil. This difference in loss could be observed quite readily.

The paper states that the observed rise of the top coil above the surrounding oil was 15.8 deg C and of the bottom coil 15.1 deg C. Since the oil surrounding the bottom coil is perhaps 10 deg C cooler than that surrounding the top coil, it appears that the temperature difference between the 2 coils is greater than the values 15.8 deg and 15.1 deg above surrounding oil would lead one to believe.

The [illegible]pedances given w[illegible] is fairly high, say 200 volts. If, however, this voltage is low, say 50 volts or lower as is often the case, the per cent lead reactance with the same current will be some 4 times or more as great. This would give impedances of the shortest and longest bars of 0.76 per cent and 1.32 per cent, respectively. Taking the winding impedance at 3.68 per cent as before we have

Total impedance of longest circuit.........5.00%
Total impedance of shortest circuit.........4.44%

In this case the top coil would take about $12^1/_2$ per cent more current and would have 26 per cent more loss than the bottom coil. It follows that there would be a marked difference in the temperatures of the 2 coils.

In closing I should like to refer to an article on furnace transformers that appeared in the *Electric Journal* of September 1933. This article describes furnace transformers of the shell form of construction with vertical coils and all leads coming from the tops of the coils. The low voltage leads are all of approximately the same length. The high voltage leads go directly to the tap changer or terminal board and do not involve the complicated arrangement shown in Fig. 3 of the Stephens and Schell paper.

Rocking Indirect Arc Electric Furnaces

Discussion of a paper by E. L. Crosby published in the January 1934 issue, p. 132–8, and presented for oral discussion at the electric furnace session of the winter convention, New York, N. Y., Jan. 23, 1934.

J. V. Alfriend, Jr.: The paper by E. L. Crosby calls attention to an electrometallurgical tool developed under the stimulating pressure of the World War; yet unlike many of the war developments this rocking indirect arc furnace has stood the test of peace time requirements.

Mention is made on page 135 to the effect that "The present tendency both here and abroad is toward a greater number of relatively smaller furnaces instead of toward the concentration of operation in a single unit." This statement must apply to a certain section of the field of electric furnaces as otherwise it must ignore certain very large arc furnace installations that have been made in this past few years. To mention a few of these that come to mind there are:

The 50-ton arc furnace at the Rotary Electric Steel Co. requiring a 10,000-kva transformer.

The 40-ton arc furnace of the Imperial Japanese Navy requiring a 12,000-kva transformer.

The 80- to 100-ton arc furnace of the Timken Roller Bearing Co. requiring 2 12,000-kva transformers.

The banks of 15-ton arc furnaces of the Ford Motor Co. each requiring a 5,000-kva transformer.

The numerous carbide and ferro-alloy furnaces each requiring transformer capacity of 3,000 kva to 5,000 kva.

It would be appreciated therefore if Mr. Crosby would define more accurately the field of application of the rocking hearth furnace and also give us an expression of his opinion as to kilowatt capacity he anticipates as the future of an individual single phase rocking hearth furnace.

It is noted that an external reactor

mounted within the transformer tank is used for the purpose of obtaining arc stability and that this reactor usually is connected to the 20-per cent reactance tap. It is further noted that the low voltage leads from the transformer are interlaced from the transformer up to connections to the furnace flexible cables for the purpose of reducing reactance. It is felt that some economy would result from a careful study of the use of noninterlaced low voltage busses with a consequent reduction in the amount of external reactance necessary.

This is not an argument in favor of noninterlaced low voltage high current bus work, as in very many instances the reactance must be kept to a minimum and interlacing is an essential. There are other furnace applications requiring adjustment in the matter of stabilizing reactance and this factor may force the apparent contradiction of interlaced bus bars and external reactors.

Clyde L. Frear: Too much emphasis cannot be placed on certain points brought up by Mr. Crosby in his excellent paper on electric furnace melting of nonferrous and ferrous metals. The writer is in entire agreement with him that the electric furnace is probably the only type of melting equipment that can use the cheapest grade of raw materials obtainable, and yet turn out the highest grade of castings. The electric furnace also permits the production of any grade of iron desired with close control of the composition and the physical properties of each grade. These excellent properties are a result of the superheating and refinement as well as the thorough mixing which the molten bath undergoes while in the furnace, with the result that the bath of metal, and also the resulting castings will be perfectly homogeneous.

Of course, Mr. Crosby does not intend to convey the impression that the rocking indirect arc type of furnace is the only kind of electric melting furnace in which the bath is thoroughly mixed. In a direct arc and in an induction furnace, in both of which the electric current passes through the metal bath, there is just as much or even more mixing of the bath than is possible by mechanically rocking the furnace. Almost any high school physics course teaches us that when an electric current passes through a conductor magnetic forces are set up around that conductor. In this case these forces will surround the direct path of the electric current but will be confined mostly to the bath of metal. As a result of these magnetic forces produced directly in the bath, there will be a continual stirring of the bath of molten metal. This stirring action, while very efficient in producing complete homogeneity of the bath, is very gentle in its action so that there is little or no chance of eroding the hearth.

As an example of this complete mixing in the direct arc furnace, the writer has added 500 lb of sheet steel scrap to one side of a 2-ton bath of molten cast iron, then allowed the furnace to run quietly on low transformer tap. In 3 minutes after this addition, samples were taken from different parts of the bath. Chemical and microscopical analysis of these samples showed complete homogeneity of the bath.

By using a direct arc furnace, a slag of any desired composition may be used on the surface of the bath, which slag is necessary for efficient refining of the metal. This slag in no way hinders the heating of the bath, in fact, a layer of slag on the surface is really an aid in heating the bath as it holds the heat in the metal. At the same time it protects the roof and side walls to such an extent that when the bath is heated to 3,000 deg F, the color of the roof is usually only a bright red.

Cast Iron and Its Production

Discussion of a paper by M. V. Healey published in the January 1934 issue, p. 120–3, and presented for oral discussion at the electric furnace session of the winter convention, New York, N. Y., Jan. 23, 1934.

Clyde L. Frear: Mr. Healey is to be congratulated upon this paper. It is the first one to come to the writer's attention that gives a distinct comparison between the cost of cast iron production in the cupola and in the electric furnace.

The writer agrees with Mr. Healey that the improved qualities of iron produced in the electric furnace are due almost entirely to the control of the graphite in the resulting castings, such control resulting from a superheating and refining which causes a controlled solution of the graphite nucleuses in the molten iron with the result that the number, size, and distribution of the graphite flakes in the solid castings are such that there will be a distinct improvement in the physical properties.

The readers of this paper may have received the impression that the electric furnace is suitable only for the production of castings having high strength, where machinability has been sacrificed to obtain these high strengths. This type of melting equipment is just as suitable for the production of the so-called soft irons. The writer has been connected with a manufacturing concern which installed an electric furnace for the production of just such castings, using as raw materials: machinery scrap, steel scrap, steel chips, and cast iron borings—in fact nearly all ferrous scrap produced by this company during its regular manufacturing operations. Soft irons can be produced as economically in the electric furnace as in the cupola. Furthermore, due to the control of the graphite precipitation, these soft irons are finer grained, and withstand higher hydraulic pressures than irons with the same machinability produced in the cupola. As a general rule it may be stated that any iron produced in the electric furnace will be finer grained and will have better physical properties than will an iron of the same machinability produced in the cupola; this may be stated in another way: an electric furnace iron will have better machinability, and will be closer grained than will a cupola iron of the same strength.

Concerning machinability, the writer, as a result of long experience, cannot agree entirely with Mr. Healey that for maximum machinability the combined carbon should be zero. In gray irons as cast, containing no free cementite, it has been the writers' experience that a combined carbon content of 0.30 to 0.50 per cent will give better all around machining properties than will a lower content. The distribution and fineness of the graphite has so much bearing upon the machinability that it is impossible to set any hard and fast rule comparing this property with the content of any single element in the iron.

The writer further agrees with Mr. Healey concerning the use of alloying elements. In a number of foundries the use of alloys has been discontinued except where specified in the purchase orders by the customer. The reason for this was that the improvement effected was not sufficient to permit the increased cost due to the use of the alloys. This lack of improvement in the properties should not be blamed upon the alloys, however, but upon the fact that the iron to which they were added was a low-grade iron in the first place, and little improvement can be effected in a low-grade iron by the addition of any alloy. Furthermore, greater improvement in properties may be produced in an unalloyed iron by refinement in the electric furnace than could be obtained by the addition of any amount of alloying elements to poor cupola metal.

High Frequency Induction Furnaces

Discussion of a paper by C. A. Adams, J. C. Hodge, and M. H. Mackusick published in the January 1934 issue, p. 194-205, and presented for oral discussion at the electric furnace session of the winter convention, New York, N. Y., Jan. 24, 1934.

P. H. Brace: During the past few years the Westinghouse company has carried out extensive investigations in the induction furnace field and a brief outline of some of our experiences with 60-cycle coreless induction furnaces may be of interest.

We started with a 100-lb unit with a 7-in. diameter crucible in which mild steel was melted successfully. Following this a brass melting unit capable of holding 800 lb was constructed and successfully operated over a period of more than a year. A variety of brass foundry alloys was handled and with few exceptions castings of superior grade were produced. The best results were obtained with manganese bronze. In the case of leaded bronzes, particularly a leaded phosphor bronze, it was found difficult to maintain the furnace lining which consisted of a preformed clay-graphite shell separated from the inductor coil by an annular packing of zircon sand. The power factor of this furnace was approximately 15 per cent with normal charge and it was found unnecessary to use a starting slug, since the pigs normally used for foundry melting stock proved quite satisfactory.

The 60-cycle idea was pursued still further and an 800- b unit was constructed and successfully operated on nickel-base alloys. In this case it was found necessary to use a starting slug and at the high melting rate, the agitation was unduly violent and caused

rapid pick-up of oxygen and nitrogen by the charge. Experiment showed that control of the furnace atmosphere would eliminate contamination of the melt. The inconvenience of the starting slug, and the need for atmosphere control, when working a fast melting schedule, caused the replacement of this furnace by a conventional high frequency unit operating at 960 cycles.

The success of the 2 small units from the melting standpoint led to the construction of a 4-ton unit powered direct from a motor generator set without capacitors. This was practical since the power factor was between 20 and 25 per cent. This unit was first applied to the melting of cast iron scrap, borings, etc., and for making miscellaneous small castings. Numerous difficulties were experienced with linings, and in the end satisfactory results were obtained with a rammed lining of sharp silica sand bonded with as little as $2^1/_2$ per cent of ball clay and prefired in place with gas. Zircon brick from the Titanium Alloy Manufacturing Company showed promise. In melting cast iron, built up linings were found difficult to maintain because the superheat required caused the temperature of the refractory at points within a short distance of the coil to rise to the melting point of the iron. Therefore any small crack allowed metal to come uncomfortably near to the coil before being stopped by freezing. It seems desirable in most cases to have a lining of granular nature firmly rammed in place and of such constitution that the space next to the metal just becomes plastic at working temperature.

Changing foundry and business conditions caused the furnace to become uneconomical for its original purpose and a number of experiments were conducted to see what could be done with it as a steel melting tool. It was found possible to remelt low-silicon and high-silicon steel scrap with little loss of silicon, and successful runs were made in which very creditable medium carbon steel was made by refining miscellaneous iron foundry scrap.

The agitation was vigorous and it was found that the progress of refining operations was very rapid. No difficulty was found in getting high temperatures. In fact, on one occasion when a charge was held molten overnight to relieve an overworked experimental crew, disaster almost occurred due to a misjudgment of the bath temperature owing to its being hidden by a layer of slag. The silica lining became plastic and began slowly to float to the top of the charge. Rising power factor readings warned of the danger in time to prevent a "break out." The charge was poured out at the first opportunity and the lining patched and used in subsequent runs without difficulty. It is our impression that a lining of nearly pure silica bonded with a minimum of clay and preheated to fit the surface before attempting normal use presents attractive possibilities where an acid hearth can be permitted.

The results of these experiments led to the conclusion that for the sizes likely to be used in the near future, frequencies higher than 60 cycles would be demanded and developments since then have provided motor generator equipment suitable for various frequencies from 120 cycles up to 5,000 cycles. These units are particularly adapted to furnace work, and I think we may be regarded as having explored the frequency field quite thoroughly from the practical standpoint over the range between 60 and 15,000 cycles.

The controlling importance with respect to the choice of frequency, of the conditions surrounding particular applications is indicated by the fact that we now have in commission units operated at 60, 360, 500, 5,000, 10,000, and 50,000 cycles ranging in capacities from 10 to 125 kw; these are in use for melting and refining and heating ferrous and nonferrous alloys and other materials in vacua, in controlled atmospheres, and in air.

All these are based on high frequency electromagnetic induction, but it may not be out of order to call attention to the fact that high frequency electrostatic induction is showing some interesting possibilities in connection with processes that may become of interest to electrometallurgists.

Electric Power Switching

A. H. Lovell, January 1934 issue, p. 147–8.

Switching at the Hudson Avenue Station

C. M. Gilt, December 1933 issue, p. 868–75.

Switching at Richmond Station

Raymond Bailey and F. R. Ford, January 1934 issue, p. 156–61.

Switching at Long Beach Plant No. 3

A. A. Kroneberg, O. R. Bulkley, W. A. Andree, December 1933 issue, p. 826–30.

Switching at the Connors Creek Plant

A. P. Fugill, January 1933 issue, p. 162–8.

Switching at State Line Station

T. C. White, January 1934 issue, p. 148–56.

Discussion of a symposium presented for oral discussion at the session on electric power switching of the winter convention, New York, N. Y., Jan. 23, 1934.

F. H. Hollister: To open the discussion this afternoon on the papers on switching energy, perhaps it would not be out of place for me to give, briefly, some observations with respect to each of the 5 papers, and then follow with a few remarks regarding trends as gleaned from a review of the plants taken as a group.

The paper on the Hudson Avenue station indicates how rapidly stations may grow, and how they develop in size of units in switching and bus equipments, also how the engineer's conception of the general problem of plant design and operation may be affected and changed by a rapidly growing demand for power. Changing factors, such as amount and location of bulk load demand, often force serious consideration of a change in fundamental plans and arrangements. At this station, with a plant growth and demand apparently unexpected, the margin in breaker rupturing capacity was rapidly overtaken. The scheme of feeder supply to the substations interests me very much, also the ingenious expedient of a synchronizing or tie bus for tying bus groups together with load transfer and for back-up supply when the occasion requires.

The paper on Richmond station supplies considerable food for thought. Many important design features are suggested for future study and development, particularly in oil circuit breakers. The author has been very frank in giving a report of their troubles, which apparently have been very serious. Of much interest is the author's brief review of the experience with and description of the connections between generators and busses. We note also the emphasis placed upon the straight double bus scheme with selector circuit breakers for switching to give maximum operating simplicity and reliability.

The paper on the Essex-Connors Creek station is of particular interest in showing how a radial system can be expanded to take care of increased demand. It describes also the new developments in metal enclosed equipment, tube busses and oilless circuit breakers. The author concludes that if a new station were being built today, it would be essentially a duplicate, and indicates also that there have been no system or equipment difficulties or troubles worthy of note. I am wondering if in these 2 respects the answer will be the same 5 or even 3 years hence?

The paper on the Long Beach plant and the discussions should appeal to those who have the problem of linking together large blocks of power from hydroelectric and steam-electric stations separated by long distances. Of outstanding interest also are: the scheme for paralleling on high voltage; the method of control of short circuits; the unit plan for generators and transformers; the automatic frequency control, and the quick starting turbine-generators at Long Beach.

The paper on State Line describes in a general way the initial installation and scheme of connection and operation for a bulk power station where the most of the load is taken out at 66,000 volts under-

ground. The outstanding design features of note are: the double ring bus system of connections, the use of 22-kv metal-clad switchgear, and the large capacity of generators and feeders.

As regards trends, when I read these papers I reviewed them with the idea of seeing whether I could find any major trends, considered in a broad sense, and it seemed to me there were a few general conclusions that might be drawn.

Looking into the future, having in mind particularly large power stations for large power consuming areas, generating at a suitable voltage, and transmitting some distance, say, 3 to 15 miles, to load centers or substations, or 30 to 75 miles or more to high voltage terminal stations or subtransmission systems, I feel that we shall see more and more installations of generators and step-up transformers handled as units and bussed at some higher voltage. Trenton Channel in operation in 1925 is an early example of the former, except it has low voltage as well as high voltage switching, and Philo No. 3 triple unit, in operation in 1927, is an example of the latter. Such is also broadly and recently illustrated by Long Beach. The economic considerations, and to some degree continuity, reliability, and safety of service, will force that result, however much one may not want to give up a system scheme of generation and transmission upon which he is already launched. There will be many involved engineering problems to analyze carefully and to solve. An important one will be system stability, requiring the study of generator and transformer reactances, short-circuit bus excitation, system voltage regulation, speed of relays and oil circuit breakers, etc.

I believe we shall see more high voltage (66-kv and 132-kv) transmission terminals located near the theoretical load centers of areas of distribution and low voltage substations. Low voltage, high current capacity, expensive switching installations at generator voltage, with complicated and hazardous interlocking arrangements are sometimes necessary, but in this industry, which has not yet reached its ultimate possibilities, many power stations are already weighted down with serious problems arising from their present switching schemes.

I look forward to and hope for the day when the major power stations will be more strictly "power stations," considered electrically, and not a combination power station, high voltage terminal station, and low voltage distribution station all in one. Naturally the situation where power stations can be treated as one problem, terminals as another problem, and substations as still another problem, is ideal for the designing engineers, but that is not the reason I am emphasizing this point. It is true, we will probably never be able to do without the combination arrangements. Under many conditions, combination electrical station switching arrangements are economical and therefore of distinct advantage, but in the case of power generated at one place and transmitted several miles at generator voltage, say, at some voltage between 11,000 to 22,000 volts, to several low voltage distribution substations, a thorough and comprehensive study might possibly reveal that economics would dictate quite a radically different system arrangement. The correct solution from a system planning engineer's point of view is often obscured by close association with a system scheme adopted when load demands were small and scattered, when the art had not progressed, or the developments in generation, cables, and switching reached the place where we find them today. Why not generate at some suitable voltage, and step up directly by autotransformers if you like, to 66,000 volts for large stations with large power demands in large cities, and to 130,000 or 220,000 volts for such situations as Long Beach? Eliminate the low voltage switching at the power stations to a considerable degree; save and relieve the congestion of switching and large cables at power stations; provide more simple plant operation; work for greater reliability, therefore for greater continuity of service and less hazard to men and equipment; and withal secure marked economies in investments.

Another major trend I would mention, that I think I see, more or less paralleling the above, but adapted more especially to cities like Kansas City and Cincinnati, is that I believe American engineers are going to adopt and some day use more extensively still higher voltage generators and distribute at generator voltage. Generator designing engineers have said that 16,000 to 18,000 volts is the best voltage for which to design large generators, taking all factors into consideration. That may be true today, but who will say that it is always going to be true? I do not believe the possibilities in generator design have been exhausted.

In England, some of the engineers for utility companies coming under the scope of the activities of the Central Electricity Board, who are working for one large unified power system for Great Britain, are finding it not only possible but feasible, more efficient and economical to use 33-kv to 36-kv generators. C. A. Parsons & Co. have built 7 machines for 33 kv to 36 kv. The first one—a 25,000-kw unit—has been in successful operation since August 1928. It is reported this company is ready to wind direct for 50-kv certainly, and perhaps as much as 66-kv, in units of from 25,000-kw to 75,000-kw capacity. I would like to hear what the American manufacturers' designers have to say on this subject!

Some of the papers refer to troubles and developments in circuit breakers, and these indicate still another major trend which possibly might better be spoken of as a "continuing and expected improvement," namely: toward better circuit breakers and relaying, or switching in its larger sense. I feel sure there will be further developments in circuit breaker design and use. It seems to me that circuit breaker designers are barely keeping pace with other improvements in the power plant field, particularly as regards rupturing capacity, current carrying capacity, operation, reliability, method of breaking the arc, and other details in construction.

H. Y. Hall: The papers presented here today indicate that switching equipment used in the large electric power systems is still far from standardized, in fact it appears to be in a state of flux. Not only are radical changes being made in the switches themselves, but methods of assembly and arrangements of the various elements of a complete switching station vary greatly.

The fact that all the stations described have given such satisfactory service speaks well for the equipment itself, the station designers, and also for the skill and care of the operating personnel.

Apparently the trend is away from the isolated phase concrete construction exemplified by earlier stations, including Richmond and to some extent Hudson Avenue, and toward some form of metal clad construction.

Essex uses air insulated switching and is attempting to reduce the amount of oil used to a minimum. In line with their desire to eliminate entirely the oil in future installations, they have made a trial installation of the new deion circuit breaker. All of us are oil fire conscious these days and realize that as long as oil is used, there will always be trouble from oil leaks and danger of oil explosions and until a noninflammable substitute for oil is obtainable at a reasonable price, it will be impossible to entirely eliminate dangerous oil fire hazards.

A recent transformer oil fire at Hell Gate illustrates this. The explosion of a 27-kv pothead shot a piece of casting into and punctured the radiator of the adjoining transformer, letting out a stream of oil, which sprayed onto the hot pothead and ignited. Both the compound in the pothead and the oil caught fire and considerable damage was done to overhead bus work and switches before it could be extinguished. This experience indicates the need of a rugged barrier between the pothead and the transformer, so that flying pothead parts will be prevented from striking the transformer radiators, especially where the radiators are made of very thin metal. It also indicated the desirability of providing each radiator with valves.

Such an explosion might conceivably occur in any of the oil or compound-filled metal-clad switching stations and with a large supply of oil available to feed a fire, it is possible that considerable damage might be done, not only to the equipment itself, but also to adjacent structural work. Also, the hazard to operating personnel is always present.

As pointed out in the State Line paper, there are very real restrictions imposed on the maintenance of outdoor switching equipment during several months of the year. Even the changes suggested by T. C. White, would not, in our opinion, satisfactorily overcome the difficulty where the winters are cold and snow storms frequent. In extensive switching stations where equipment is heavy, the unfavorable working conditions might be a serious matter, especially if a major failure should occur. For heavy equipment, men especially trained for that class of work are required and it greatly simplifies the problem of organizing a suitable maintenance crew if a few men with the proper training can be kept busy on the necessary inspection and maintenance work throughout the year. In this way, defects can be remedied promptly before serious failures occur.

One advantage of the metal clad switchgear cited at Essex station is that better protection to busses and equipment may be obtained by insulating all metal enclosures, except for ground connections, and so by this means obtain simple and reliable relay protection against faults in all busses and switching apparatus. Apparently this has

not been done at State Line; possibly they did not think the additional expense justified. Perhaps Mr. White can enlighten us on this point.

Unless the ground connections to these insulated enclosures are properly installed and maintained, they might present a real hazard to the operating personnel during short-circuit periods.

One advantage of the metal enclosures, not stated, is the greatly reduced thickness of the barrier, permitting a corresponding reduction of switch center dimensions. Essex claims short length of busses resulting from the arrangement used.

Although it does not appear so on first thought, it is a fact that for the same switch-pot centers, the length of busses for a segregated phase system is about one third of that for the mixed phase system. All circuit breakers now in use on segregated phase systems have tanks so large that they are placed on 3-ft to 4-ft centers. A segregated phase system using deion type breakers and metal enclosures would be economical of busses and also of floor space.

Both Hudson Avenue and Essex make use of an equalizer or synchronizing bus for better distribution of load to the power sources. Hudson Avenue makes use of a very unusual and ingenious bus arrangement which they term "star bus" in absence of a more fitting term. It is a flexible arrangement particularly with respect to generator connections. In the case of Essex, according to the diagram submitted, interconnections to other power stations can be obtained only through the equalizer bus as a medium and if it should be out of service for any reason, apparently the station ties would have to be cut out.

Sectionalized duplicate ring busses provide a very reliable and flexible arrangement and the simple layout is easy to operate. We are inclined to agree with the author of the State Line paper that this is the most desirable arrangement to meet all requirements.

In recent years many of the power stations have become so large with reference to the systems supplied, and continuous power supply so important, that some companies have found it advisable to operate stations in 2 or more distinct parts on the electrical end (and also on the steam end as far as practical) so as to minimize the extent of any major fault that might occur. These separate sections are usually further subdivided by reactors into small groups of feeders. Moreover, when feeding into distribution network system with their transformer and network protectors, problems of voltage and phase angle control become important considerations.

With the above conditions in mind, the wisdom of installing very large turbine-generator units is open to question. In addition to the usual objections to such large units, such as the large reduction of station capacity when they are out of service for repairs, the larger reserve capacity required to replace possible outage and the uneconomical loadings of very large units, there are difficulties of distribution of the output to different bus sections, which under present-day layouts is usually required. The difficulties referred to are those of voltage and phase angle control on the branch circuits of the generator or its direct connected step-up transformer. The use of double-wound generators does not overcome these difficulties.

Smaller generators meet the above requirements much better and should be just as economical. Also their use would reduce the required rupturing capacity, size, and cost of switching equipment. The lower cost per kilowatt of very large units is largely offset by the necessity of supplying additional reserve capacity above that of the small unit installation.

In this connection, it is interesting to note that State Line No. 2 unit is 50,000-kw smaller than No. 1 unit.

Richmond Station is using copper channel with frequent expansion joints for connecting the 165,000-kw generator to the bus. For this purpose, large stranded rope center copper cables possess some distinctive advantages, especially when it is desired to use insulated conductors.

J. K. Ostrander: An analysis of the various systems of connections for main bus circuits applying to all large power stations constructed during the past 25 years would show that by far the most common system is the one with 2 main busses, to which all circuits are connected by 2 selector oil circuit breakers. In most cases the busses are sectionalized with reactors in the bus or in the individual circuits.

This system of connections has become almost a universal standard, probably because of the indisputable merits of such an arrangement. However, many power stations of the future for several reasons will not follow this design. First, problems of economy may prevent the use of more duplicate equipment than is absolutely necessary; second, problems peculiar to the very large station may dictate other courses of procedure; and third, interconnection of stations, such as is now quite common practice, has a tendency to make unnecessary most of the duplication of equipment formerly considered essential. In many power systems it is possible to lose a generating unit with all the electrical circuits associated with it, without any adverse effect on the load.

It is quite possible that conditions over which the operating company has no control, such as the necessity for lower property costs to make possible unavoidable low rate schedules, may make it necessary to give more attention to the cost element than heretofore required.

The future cost of transmission and distribution per kilowatt of energy generated will undoubtedly be reduced from necessity. If a 13,000 or 26,000-volt feeder be connected to the station bus with a circuit breaker installation costing more than the feeder itself, any saving effected in the distribution system may be offset by excessive costs in the switching equipment group of apparatus. This does not mean that a sacrifice must be made in operating reliability. During recent years great improvement has been made in circuit breaker design and breakers rarely fail in service. Development of the metal-clad equipment has not only reduced the liability to failure but has made it possible to localize the disturbance if failure occurs.

A system of connections using only one circuit breaker per feeder, as provided at Hudson Avenue and Connors Creek, indicates how duplication of equipment may be avoided without sacrifice of reliability.

In general, unit costs are reduced as the size of the station is increased but this is not necessarily true of the switching equipment. In fact the large size of the station may in itself be the cause of high unit costs for the electrical installation.

Considering the electrical system only, it should be more economical to build a group of moderate size stations than one very large station. This is chiefly due to the expensive equipment necessitated by a large concentration of power on the bus. The expedient of designing the large station so that it becomes similar in its electrical connections to a group of smaller stations is often quite effective in reducing costs.

Synchronizing at the load is one means for accomplishing this result. Another is the use of the synchronizing bus which has possibilities of being very effective under certain conditions. The bus connections at both Hudson Avenue and Connors Creek provide one apparently successful method of coping with the problems incident to a large concentration of power on a single bus.

Several recently constructed stations have apparently obtained good results from the use of the fault bus. The principle of this device is no doubt good but it has the objection of introducing complexities into the layout of the switching equipment. Before the fault bus scheme is adopted, I believe a strong effort should be made to devise a simple and effective system of differential protection which does not require any special type of construction for the bus and its connections.

A generating station whose load is transmitted by a comparatively few high voltage circuits generally requires a radically different electrical design from that of a station with a large number of low voltage circuits. Due to the high investment in each transmission line, it is highly important that no line shall be out of service due to outage of switching equipment; therefore a high investment may properly be made for the switching equipment of each line. Duplicate busses and other elements of high cost may be justified. The systems of connections used for the State Line and Long Beach plants are good examples of what might be proper for this type of station.

K. C. Randall: The committee sponsoring this switchgear symposium and the authors who have contributed papers are to be congratulated on the very interesting and informative data which has been presented. A. H. Lovell pointed out that although originally an economic survey was contemplated, it could not be carried out. In such a survey of these stations with their widely differing generating capacities, bus arrangements, and types of load, it is immediately apparent that any attempt to set down dollars against results will be very difficult. In 10 years—1922 to 1932—from the earliest (Hudson Avenue) to the latest (Essex) both apparatus and assembly designs have progressed, naturally reflecting those years of research, design, manufacture, and operation. It would not be fair to compare directly such structures, built 10 years apart, even were they intended for identical conditions, which is not the case. Never-

theless, much data is given to warrant some conclusions of an economic nature.

The first of these stations used metal-built gear for its auxiliaries and so do the others. That original gear has performed satisfactorily, but it in no way compares with the present designs. The recent advance in the coördination of apparatus design and assembly design is conspicuous. Where formerly individually good apparatus was available, now completely assembled equipments are available in which the separate devices are coördinated, both mechanically and electrically, into a harmonious functioning whole. Such factory-finished, tested and proved, fully assembled equipment, is shipped ready to run. Formerly, it was common practice to spend a lot of time and money in the field in detailed checking of wiring and mechanical clearances. The equipment had to be proved and that was the way of doing it. Better designs and improved manufacturing facilities have of course done much toward this progress, but extensive and very heavily powered testing equipment has contributed most to making tests, where previously only opinions prevailed.

The economies from convenience in shipping, handling and ease of installation of fully assembled equipment are distinctly a case of foreseen problems matched with a carefully planned design. The reliability of the ultimate service is not only considered, but also the time, effort, and cost previous to beginning regular operation.

Modern metal-built gear is adaptable to every power purpose regardless of capacity. The high order of demonstrated reliability of this type of equipment is significant. It is already generally used for station auxiliaries and in a number of cases for the main switchgear. It is interesing to note that the initially planned periods for inspection and maintenance are gradually extended as experience justifies this increased confidence and associated economy. Surge trouble immunity is also significant in the fact of recorded experience of very high peak values.

To summarize: the evidence of these papers certainly suggests economic justification is thoroughly back of the increasing use to which we find metal-built gear is being put.

C. H. Sanderson: The 5 papers comprising this symposium serve as illustrations of the lack of similarity in the design of switching equipments for generating stations. They are the product of dissimilar specifications; therefore, the dissimilarity of design was inevitable. The same may be said of any other group of stations.

Even though the designs were based upon identical specifications it is quite probable that they would still be lacking in similarity as has been indicated recently in the various solutions to hypothetical problems. This also is inevitable, as there are so many ways of arriving at some kind of a solution. As C. M. Gilt has said in his conclusion, choice often has to be made between the advantages and limitations of one design and the somewhat different advantages and limitations of another. And in the same paragraph he has given the words for a legend which might be placed over the door of any station—a compromise between cost and a closer approach to technical perfection.

One feature, however, in which similarity appears to indicate more than a trend is the group operation of equipment. The single or solid bus and the closed ring bus have given way to the operation of the station and system in groups or sections with proper relay protection to localize troubles that otherwise might be system disturbances.

Differential protection of group busses appears to be giving satisfactory operation. Every one will agree, however, that it should not be called upon to demonstrate under operating conditions if this can be avoided at any reasonable expense. The insulation of the busses and connections thereto at least as far as the first protective breakers, also between generator and breaker, merits particular attention. Dependence upon many single porcelain units within this area appears to be a potential hazard which might be greatly reduced by the use of other forms of insulation having a less abrupt characteristic of deterioration and, therefore, more subject to control through some method of periodic testing.

The disconnecting device between bus or generator and the first protective breaker is another potential source of serious trouble. The bayonet type disconnectors employed with the elevating or truck type breakers have given some trouble. One recent instance is recalled where an entire plant was shut down because of failure of the bayonet type connector between a generator and its breaker. For the more important locations the conventional knife switch disconnect or the later oil insulated disconnect appear to be more dependable and more readily maintained.

The State Line installation has contributed greatly to the perfection of heavy duty outdoor switching equipment. It has a good operating record and the popularity of oil filled metal clad switching equipment has increased in that district. However, considering the suggested improvements, such as adding of decking and siding, and control system safeguarding, and considering weather conditions in the northern states as they affect the equipment and its ready maintenance, especially for circuits of such great capacity and importance, it would seem that an enclosure as represented by an inexpensive form of building shell, with low roof and sides, permitting some decrease in cost of equipment and considerable decreased cost and added convenience in maintenance, would provide an installation which would prove a serious competitor.

The Essex switching station at Connors Creek is of particular interest as it is the culmination of many years of experience in the design and operation of this class of equipment. Future operating and maintenance experience will be of general interest because of the elimination of formerly used housing materials for metal compartments and housings throughout.

The use of armored control cable is another step in advance and should prove cheaper in cost and maintenance or extension than any form of rigid conduit installation.

The Hudson Avenue ground and test switches, partially shown in Fig. 6 of that paper, should be of particular interest wherever 2 or more feeders are to be connected to a single feeder circuit breaker, especially where the feeders supply network load. By means of this device any feeder may be opened under load without disturbing the others, may be left free, or grounded or connected to the test bus. They may be designed for manual or electrical remote operation or a combination of both. It is to be hoped that the manufacturers will produce a simplified and compact design at moderate cost so that their application can be greatly extended.

Philip Sporn: Station and substation design papers have altogether too frequently been open to the criticism that they give a description of what has already been accomplished and do not go into the fundamental basis of design, with the result that they are of little use to the practicing engineer or the student trying to find out the "whys and wherefores" of the existing practice. In this regard the aim for this symposium, as stated by Professor Lovell, is entirely praiseworthy and it is to be regretted that the papers as a whole do not stand up when measured by this criterion.

Professor Lovell states that the trend is toward higher voltage for bussing at the generating stations, and even for the generators. I do not believe that any general statement that a tendency for the generator voltage to go upwards is true. In the case of the Philo 165,000-kw unit, a generator voltage of 11,000 volts was selected and if this machine were being installed today I believe that it would be at the same voltage. We recently had a case in connection with the rebuilding of a small hydroelectric plant in which the original generators were designed for 13.2 kv. A study of this particular plant showed that 4,150 volts was the most economical design. In another case 6,900 volts was originally considered but 4,000 volts was finally used. Each case must receive individual attention before the generator voltage can be determined, and it is a case of considering the combination machine and switching design and not simply a question of amperes to be switched.

The paper on State Line station is an elaboration of the paper on the same subject presented about 4 years ago by A. M. Rossman, and was discussed at that time by several, including the speaker. There are, however, 2 points I should like to call attention to in connection with this paper:

1. In the original discussions as to the safety and the economics of this type of switching, the discussion mainly centered around the question of whether or not the economics were sound. One of the factors that influenced the choice of outdoor gear was the expected greater safety of outdoor equipment. It is interesting to note that at another station having the same type of switchgear, there occurred about 2 years ago one of the most disastrous fires ever experienced at a power station.

2. The economics of the plan which were discussed and questioned at the time Mr. Rossman's paper was presented are, I believe, still not settled and personally I doubt if today the economics of this type of gear are particularly favorable.

The paper by Raymond Bailey and F. R. Ford covering the Richmond station of the Philadelphia Electric Company is a descriptive paper and is open to the same criticism previously indicated; namely, that the authors do not thoroughly discuss the basic reasoning behind the adoption of the particular switching arrangement.

The paper by A. P. Fugill covering the switching station for Connors Creek is again in the descriptive class, but the infor-

mation is of special interest in that it does show that considerable progress has been made toward simplifying the switching scheme. The operation of the generator and transformer as a unit and tied to a single main bus and the elimination of high voltage breakers at the distribution substation, shows progress in the simplification of switching. Comparing this switching arrangement, for example, with Fig. 2 of the paper by Messrs. Bailey and Ford, one cannot help but raise the question whether the Richmond layout having 2 busses with selector breakers and in certain cases 2 switches in series can be justified in any but the rarest cases.

Mr. Gilt's paper on the Hudson Avenue station shows a switching layout that is somewhat similar to that of Connors Creek. However, Connors Creek having been built later than Hudson Avenue, shows, as would be expected, further progress toward simplification. It is interesting to note that after careful consideration it was decided that one feeder breaker per feeder at the generating station was all that could be justified when considered from the standpoint of costs, complications, and hazards. I believe that thorough consideration of all factors involved will lead to similar conclusion in 9 out of 10 cases.

At the Hudson Avenue station reactors are used in the radial feeders; it is interesting to note that for Connors Creek switching station a study of costs showed that it would be cheaper to use the higher interrupting capacity breaker and eliminate reactors. This difference in practice may be and probably is entirely due to progress made in breaker design in the period intervening between the time when the 2 designs were laid down.

There are 3 points I should like to make in connection with the paper covering the switching at Long Beach plant No. 3. The authors mention that they recently found that it was possible to synchronize by means of the 220-kv oil circuit breakers rather than the generator oil circuit breakers. On our own system we have been following the practice of synchronizing by means of the 132-kv oil circuit breakers since about 1925. Prior to that time breakers were included on the generator side because it was felt that there might be some difficulty in synchronizing on the high voltage side.

While it has no particular bearing on the switching, I should like to say a few words with reference to the subject of frequency control. The authors state that on their system they hold speed within a fraction of a cycle so as to maintain an average frequency of exactly 50 cycles over longer periods of time and that sudden swings of 10,000 kw are a rule rather than an exception. An average frequency of exactly 50 cycles over long periods of time does not, of course, mean anything nor is this an indication of good frequency regulation. On some of the large eastern interconnected systems it has been found advisable to hold frequency within very close limits at all times, at least within 0.1 cycle; in some cases the time deviation has been kept within 15 cycles, that is, within 0.25 sec. On the large interconnected systems about which I am speaking, swings greatly in excess of 10,000 kw are not uncommon. On these extensive interconnected systems involving several million kilowatts capacity, experience has demonstrated that economical operation demands that frequency be held at all times within about plus or minus 0.1 cycle or less. Frequency regulation and power transfer across tie lines are closely related and if frequency is not continuously closely regulated system performance invariably suffers.

Regarding the question of auxiliary power, I do not believe that either a separate house generator or a direct-connected house generator can be justified and that the only scheme that can be justified is one taking the auxiliary power off the main generator through a directly connected transformer bank. In most cases the interconnections will always furnish at least sufficient energy for starting the plant auxiliaries; anything more elaborate than the above arrangement can only be justified, therefore, by blinking at economics.

In conclusion I should like to repeat that I believe these papers are entirely too descriptive and it is to be hoped that some day we can get a symposium giving a frank analysis of a series of switching schemes, the ends aimed at, how nearly the ends were attained, and what changes, in fundamental design, in material, or in detail would be made if the switching scheme were restudied in the light of current thought and in the light of experience with the old one.

C. W. Taylor: There are references in the papers on switching of energy at power stations to certain fundamentals that are of particular interest to the designer of switching stations, as follows:

The double bus arrangement with sectionalizing reactors has been recognized as having considerable flexibility, but State Line has had occasion to use some of the less frequent switching combinations during normal operation, as indicated in T. C. White's paper. The particular system of major transmission connections existent in and around Chicago, combined with the unforeseen changes in load conditions and the interrupted construction schedule, have introduced operating problems at State Line station requiring redistribution of load among the feeders paralleled or tied together at remote points of the system. It was found possible with the twin busses to select the switching so that advantage could be taken temporarily of the bus reactors as a load balancing agent. With the unexpected advanced installation of a large feeder without its intended source of power, it was found a certain section of the bus would be overloaded, but by using a section of the reserve bus this could be avoided.

The development of switching and current handling facilities has scarcely kept pace with the demand for larger power circuits, and to some degree has retarded the use of large circuits. Some designers therefore have resorted to higher voltages. It is gratifying to note that where higher generating voltages have been used, apparently no real difficulties have been encountered because of the higher voltage, up to and including 22,000 volts, so that now probably 33,000 volts would prove satisfactory.

The advantages of ground fault protection have been recognized for a number of years by many engineers. The metal-clad design is particularly adapted for this form of protection of the bus structure. This is true whether it is a metal cell structure of a more or less conventional design assembled in the field, or a so-called unit type metal-clad gear built in the factory; whether it is installed indoors or outdoors. It will be noted both the Essex and the State Line stations, where metal enclosures are used, have sectionalized ground fault protection.

Interlocking has been one of the designer's problems in providing safety features. He has resorted to electrical and mechanical interlocks, and combinations of the 2, and in some cases has purposely omitted interlocks almost entirely. They are liable to become intricate and cumbersome, even to the extent of becoming a hazard in themselves. Irrespective of whether the designer tries to go the limit, or to restrict himself to the minimum, the factory built metal-clad unit design lends itself to the maximum degree of safety as to interlocking features, with the greatest degree of ruggedness and simplicity, and because of its inherent design, the minimum number of gadgets with a greater degree of precision.

Fire hazards have been referred to in some of the papers. Most designers give some consideration to hazards from indoor switching, but, except to meet the insurance companies' requirements, there seems to be a tendency to give this subject only a casual consideration in other respects. Insurance regulations must necessarily be quite general and therefore are a poor guide for design. There have been instances where a sufficient amount of training of the operators on duty in the proper use of perfectly good fire fighting equipment has been conspicuous by its absence. Combine this condition with a fear of explosion at a switching or transformer station, and the opportunities of a good fire are unlimited. It would be of value to the operators and designers of switching and power stations if a complete report of all fires could be made available for comparison and study, such a report to describe the relative location and details of equipment, operating conditions, cause of fire, how combatted, and suggestions as to how fire could have been avoided or its severity decreased.

H. L. Wallau: The method of operating our 132-kv lines is very similar to that outlined for the 220-kv lines of the Southern California system.

The fundamental idea involved is that high voltage lines shall not be operated in parallel. At both the Avon and the Ashtabula plants the generators supply unit busses which in turn feed step-up transformer banks connected to individual high voltage lines.

There is also provided a 13-kv synchronizing bus to which the generator unit busses are connected through reactors. This connection enables the kilowatt loading of the generators to be equalized and also enables their operation at different voltages (within the plus or minus 5 per cent range permissible) thereby providing some control over the reactive output of the generating units.

At the receiving stations paralleling is done on the low voltage side. Opening the synchronizing bus tie breakers at the generating plants permits operating synchronized at the load.

The means of providing reliable supply

for auxiliaries has been previously discussed. (See A.I.E.E. TRANS., v. 51, 1932, p. 349–50.)

This 132-kv system, now comprising 416 miles of 3-phase, 4/0 circuit, is tied into the Lake Shore plant through 2 ties, each consisting of a 132 to 66-kv and a 66 to 11-kv transformer bank joined by 8 miles of 66-kv underground circuit. No high voltage paralleling occurs in this connection.

It is evident that for this system also the transmission lines and transformers operate in parallel to the load and in series to a short circuit.

It has been calculated that with these 3 plants fully developed to their expected maximal combined capacity of 1,000,000 kva and no interconnections with other systems the maximum short circuit to be interrupted will be, line to ground, 260,000 kva, and 3-phase, 730,000 kva. With the existing interconnections closed, these values increase to approximately 325,000 kva for line to ground, and 975,000 kva for 3-phase. Interrupting ratings of breakers called upon to perform this duty are 1,500,000 kva.

That these short-circuit values are much lower than would be obtained with parallel operation of high voltage circuits is illustrated by the following (d-c board) calculation.

A bushing failure at a time of light load when all interconnection ties were open produced a line to ground short circuit of 133,000 kva. Under similar conditions, except for line operation paralleled on the high voltage side, its value would have been about 312,000 kva, a value almost as great as calculations indicate will result when the complete development has taken place.

Auditory Perspective—Basic Requirements

Harvey Fletcher, January 1934 issue, p. 9–11.

Auditory Perspective—Physical Factors

J. C. Steinberg and W. B. Snow, January 1934 issue, p. 12–17.

Auditory Perspective—Loud Speakers and Microphones

E. C. Wente and A. L. Thuras, January 1934 issue, p. 17–24.

Auditory Perspective—Amplifiers

E. O. Scriven, January 1934 issue, p. 25–8.

Auditory Perspective—Transmission Lines

H. A. Affel, R. W. Chesnut, and R. H. Mills, January 1934 issue, p. 28–32, 214–6.

Auditory Perspective—System Adaptation

E. H. Bedell and Iden Kerney, January 1934 issue, p. 216–9.

Discussion of a group of papers presented for oral discussion at the session on communication at the winter convention, New York, N. Y., Jan. 24, 1934.

H. H. Spencer: [Ed. Note: This discussion deals primarily with the subject of radio transmission of music and its reproduction in homes, whereas the papers of the symposium under discussion deal with wire transmission of music and its reproduction in large halls.] The remarkable achievement of transmitting and reproducing symphonic programs so that auditory perspective is maintained should not tempt us to neglect some of the more fundamental factors which contribute to satisfactory musical reception. One of these is the variation in relative loudness level throughout a given selection; the quality in a performance which musicians frequently refer to as color.

Careful monitoring of the transmission circuits either manually or automatically can eliminate most of the unintentional variation in energy level at the transmitting antenna. The development of modern receiver circuits utilizing automatic volume control further protects the fidelity of the signals up to the loudspeaker. The problem still exists, however, for the listener to adjust the average volume of his loud speaker output on the one hand so that the loudest passages will not be unpleasant either from distortion due to overload of the receiver or simply from being too loud for the location of the receiver, and on the other hand so that the softest passages will not be lost.

It would seem to be entirely practical just before the start of a symphonic program for the transmitting station to broadcast a test note. The listeners would be instructed to adjust the output level of their sets to bring this note just to the threshold of audibility. By prearrangement with the performing artist—the conductor in the case of symphonic broadcast—the transmitted energy level of the test note could be so adjusted that the entire program would be within the range of high grade receivers.

The listener then would be relieved of the distraction of having to find the correct volume level adjustment by repeated trial. The artist would have the gratifying assurance that the listeners were receiving the program with exactly the same color as his original performance.

Stabilized Feed-Back Amplifiers

Discussion of a paper by H. S. Black published in the January 1934 issue, p. 114–20, and presented for oral discussion at the committee on communication of the winter convention, New York, N. Y., Jan. 24, 1934.

G. Ireland: To engineers concerned with the operation of the long distance telephone plant the many transmission advantages of the stabilized feed-back amplifier, as outlined by H. S. Black (ELEC. ENGG., Jan. 1934, p. 114–20), will be welcome; those involving greater stability and freedom from modulation effects being of especial importance.

With the long toll cable circuits of today involving a considerable number of voice frequency telephone repeaters, variations in the overall net losses of the circuit represent one of the important limitations on the minimum net losses that can be obtained. With the greater number of repeaters to be used in cable carrier circuits of the future and the greater gains and attenuations involved the problem of holding the circuit variations to a low value becomes more difficult. Consequently, the arrangements described by Mr. Black which, under normal maintenance conditions, practically removes the amplifiers in the circuits as a source of variations will be very helpful. Furthermore, the freedom of these amplifiers from variations and modulation effects not only will simplify the circuit maintenance but in the future is expected to permit the operation of the additional stations, which will be required, on a partially attended or unattended basis. Also, transmission testing equipment can be provided which will be capable of measuring large gains and losses and yet through the application of the feed-back arrangements to the vacuum tubes in the testing circuits will be much less subject to changes in battery voltages which will require recalibration of the measuring equipment.

Although the first vacuum tube telephone repeater was not placed in operation in the telephone plant until about 1913, today there are more than 100,000 telephone repeaters and about 4,000 carrier amplifiers in the telephone plant of the United States. Nearly half the telephone repeaters are of the 4-wire type and are applied to the 4-wire circuits employed for distances of more than about 150 miles.

Looking to the future application of stabilized feed-back amplifiers, it is probable that practically all new carrier repeaters in the future on both open wire and cable will be of the stabilized feed-back type. Since the cable in carrier systems of the future is expected to be used not only for the longer circuits, but also circuits as short as 100 miles or less in length, it is probable that the stabilized carrier repeaters will be largely used where 4-wire repeaters have been used in the past and in some cases where 2-wire cable circuits and repeaters have been used. Consequently, it is expected to find very important application in both the toll cable and open wire plant of the Bell System. In addition, it is expected to be used in the future on transmission testing equipment, as noted previously in connection with program amplifiers and even in the voice field

where perhaps greater emphasis may be placed on the securing of economies in the design of the amplifiers through the application of the feed-back principal. In conclusion, it may, therefore, be stated that the stabilized feed-back repeater should find very general application in the telephone plant and due both to its extended application and its many advantages should considerably change and simplify the present method of operating and maintaining long distance telephone circuits.

H. W. Dudley: The stabilized feed-back discussed by H. S. Black (Elec. Engg., Jan. 1934, p. 114–20) was tried out on a 20/500-kc amplifier. The main requirements were 0.5 watt output and 65 db gain with 25 db feed-back loss in the 20/500-kc range.

The most important problems encountered in this amplifier were: first, to get sufficient gain and, second, to prevent the amplifier from oscillating or "singing." The chief difficulties in both cases are due to stray capacitances. These produce shifts in phase that make the amplifier become unstable and oscillate at some frequency. a broad band amplifier must be made with less gain at the higher frequencies unless a better design is used. The better design may be one having better tubes or one having less stray capacitance.

The amplifier was built having two stages of voltage amplification and a power stage. The gain problem was solved by using a specially designed tube with 2 extra grids in the voltage stages and another in the power stage. One extra grid shields out the effect of the tube capacitances. In the voltage tube the second extra grid increases the gain by reducing the space charge effect; in the power tube it prevents secondary emission. The oscillation problem was overcome in part by cut-and-try methods and in part by allowing for the stray capacitances in the design.

In Fig. 1 of this discussion is shown the measured $\mu\beta$ characteristic of the first amplifier of this type that was built. It is seen that the point 1,0 (this is the stability criterion proposed by H. Nyquist in "Regeneration Theory," *Bell Syst. Tech. J.*, Jan. 1932) is not enclosed by this curve. Whenever a $\mu\beta$ measurement showed this point enclosed it was checked that the amplifier would sing

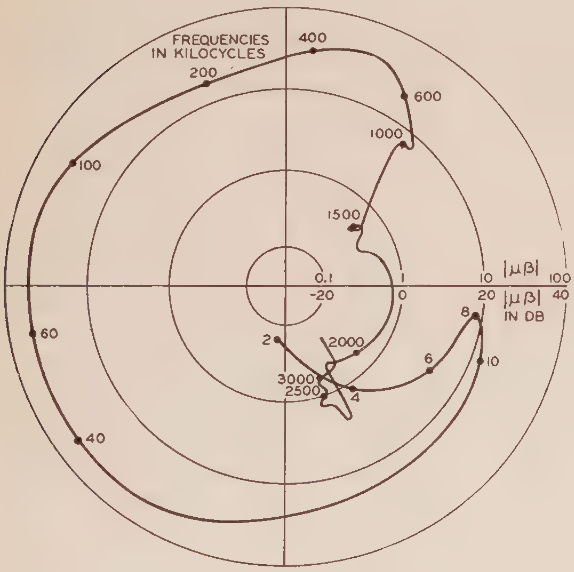


Fig. 1. Measured $\mu\beta$ characteristic of first 20/500-kc amplifier

Again the stray capacitances between vacuum tube electrodes make for low impedances. At each tube a high plate resistance is then working into a low capacitive reactance. The result is that the voltage amplification in a 3-stage amplifier drops off almost as the cube of frequency. As an example an amplifier modified to work to twice the frequency will have 18 db less gain before feed-back is applied. This means that when set up again as a feed-back amplifier. Another model of this amplifier was built having about 10 db more gain before feed-back. In Fig. 2 of this discussion is shown its measured gain-frequency characteristic. These amplifiers gave the expected improvements in general. They indicate that the feed-back principle can be used advantageously up to frequencies of 500 kc at least.

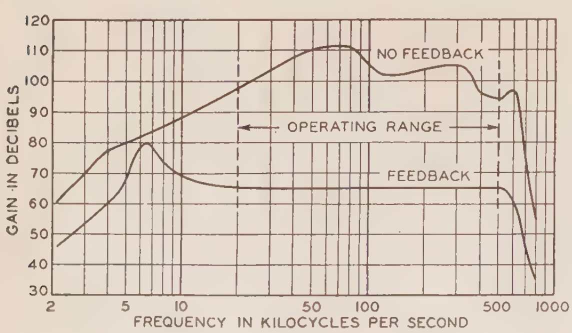


Fig. 2. Measured gain of second 20/500-kc amplifier

Petersen Coil Test on 140-Kv System

Discussion of a paper by J. R. North and J. R. Eaton published in the January 1934 issue, p. 63–74, and presented for oral discussion at the protective devices session of the winter convention, New York, N. Y., Jan. 23, 1934.

J. E. Clem: In the Appendix outlining the mathematical treatment the authors have defined C_0 as the zero sequence capacitance to ground of transmission system with one conductor grounded. This designation is not quite exact and might lead to a misunderstanding. By definition, the zero sequence capacitance of a transmission line is the capacitance to ground (and ground wires if present) of one conductor when all 3 are in parallel. This apparent inconsistency has not affected the results of the calculations because the proper value of capacitance was used.

It can easily be shown (reference 7 of paper) that the charging current in the fault which flows to ground when one line is grounded and the 2 sound lines are at phase-to-phase potential above ground is exactly the same as the current which would flow if the 3 lines were in parallel and phase-to-neutral potential applied. This is the value of capacitance which the authors actually used in their calculations.

The prime function of the device as indicated by the authors is the removal of faults from the system without anywhere near as great a shock as that occasioned by the same fault without the Petersen coil. Curves shown by the authors indicates that the exact tuning is not a requisite for the function. There is another advantage from the use of the Petersen coil and this was the purpose of the original invention. That is, the reduction of arcing ground overvoltages. When the Petersen coil is in use, it is impossible to build up arcing ground overvoltages whether or not the fault is actually extinguished and exact tuning is not a requisite for this effect.

Whether or not arcing grounds exist is a fact questioned by many. While it is true that staged tests have invariably failed to reveal their presence, it is also true that isolated delta operation in the early days was rendered exceedingly difficult and in some cases impossible by arcing grounds. From time to time a sufficient number of instances of overvoltages which can be accounted for in no other way have come to our attention, and have convinced us that they may actually occur. Present-day insulation levels are usually so high that any arcing ground which might occur is not noticed unless some piece of equipment has its flash-over lowered or insulation strength impaired by moisture, dirt, or some other cause.

In a design of Petersen coils it is essential to consider the steady circulating current which might flow. Any unbalance in the arrangement of the line conductors will set up a zero sequence voltage and this in turn will cause a circulating current to exist under steady operating conditions. The thermal capacity of the Petersen coils may have to be increased to take care of this steady current.

C. L. Gilkeson: In connection with its studies of ground fault current limitation one of the project committees of the Joint Subcommittee on Development and Research has been investigating, for the past several years, the subject of overvoltages resulting from line to ground faults on power systems. In addition to the observations on the Petersen coil system discussed by the authors, observations have been made on an extensive isolated neutral system, 2 systems grounded through neutral resistance, and one directly grounded. The voltage disturbances were recorded by automatic magnetic oscillographs which were in operation by the end of the first cycle. In all but one installation string type vibrators were used which have a fairly uniform response for frequencies up to 3,000 cycles, thus permitting a good indication of harmonic frequencies which may be present. On 2 of these systems the oscillographs were supplemented by surge recorders.

Data obtained from these installations cover periods from about $1^1/_2$ to 2 years. As expected, the highest values of overvoltages were recorded on the isolated system. It is interesting to note that for this system, which was from 600 to 800 miles in length, oscillographic records showed that only 1.3 per cent of the records obtained under fault conditions indicated voltages above 3 times normal, with a maximum of 3.9. Similar records from the systems grounded through neutral resistance, or solidly grounded, indicated no voltages exceeding 3 times normal.

In the analysis of the surge records those which indicated only highly damped figures have been attributed to lightning and therefore omitted from this analysis. Since the surge recorder indicates the time of disturbance most of the figures have been correlated with known disturbances on the system. The analysis of the surge recorder records indicates that on the isolated neutral system 13 per cent of the records exceeded 4 times normal, the maximum being about 5.4 times normal, while on the other system 2.7 per cent of the records exceeded 4 times normal, with a maximum of 4.7.

A careful inspection of the oscillograms failed to reveal any indication of the so-called arcing ground phenomenon, that is, the building up of the voltages on the sound phases due to successive restrikings of the arc. The nature of the overvoltage appeared to be 60 cycles, in some cases with lower harmonics adding slightly to the maximum value of the fundamental.

A. U. Welch: The Petersen coils mentioned in the paper are iron core reactors whose reactive kilovoltamperes are obtained by gaps in the core leg, the reactance being adjustable by means of taps in the winding. A motor driven tap changer is provided on each tank arranged for remote operation and position indication. The tap changer is interlocked with a circuit breaker so connected as to prevent current flow through the Petersen coil while taps are being changed. The general construction of the Petersen coil is similar to transformer practice and the appearance of the reactor is very similar to that of a transformer, except that only 2 bushings are provided.

A thyrite resistor permanently connected across the Petersen coil winding and mounted in oil within the tank was provided for the following reasons:

1. It was desirable to use a transformer neutral bushing based upon only the system line to neutral voltage, and in the interests of economy, to design the Petersen coil itself for only neutral voltage. Insulation for neutral voltage is quite safe enough so far as dynamic voltage is concerned, but the neutral circuit will be subjected to lightning voltages of the same or greater magnitude than the transmission line. A resistor or a lightning arrester is required to hold the impulse voltage of the neutral to a value safe for the Petersen coil insulation. The characteristics of thyrite permit its use in an oil-immersed resistor to provide adequate protection from impulse voltage, and capable of withstanding the dynamic voltage for 10 mins. For much longer duration of dynamic voltage, it would be necessary to use a lightning arrester. The resistor, when it can be used, has the practical advantages of low cost and adaptability to assembly in the same tank as the Petersen coil.

2. Operating experience with Petersen coils in other countries has shown that, if no protection is provided in the neutral circuit, impulse voltages will increase in magnitude by reflecting at the transformer neutral and may flashover the neutral bushings even when these bushings are the same as the transformer line bushings. The fact that no such trouble has occurred at this installation indicates the protective value of the resistor.

3. Certain transient circuit conditions, as, for example, nonsimultaneous opening of phases in a circuit breaker, may cause a partial series resonance and a building up of voltage. The negative resistance-current characteristic of the thyrite resistor acts to prevent this resonance and excessive voltage. The Petersen coil cannot be designed to operate at a high flux density (near saturation) on all taps. When the coil operates on the high reactance taps, the resistor offers the only method of limiting voltage rise.

I would like to point out that there are several methods of neutralizing the residual in-phase current in the arc. These schemes involve switching a voltage taken from the transmission line into an auxiliary neutral circuit. The application of residual current compensation will permit self-extinction of line to ground faults on a power system of any size.

A. P. Schnyder: Supplementing the authors' description of tests and discussions of the results obtained, a word emphasizing the fundamental purpose of the Petersen coil and other equivalent equipment of various European manufacturers may be in place. Such equipments prevent disturbance on or damage to the transmission line as caused by line-to-ground faults, which according to the authors constituted 75 per cent of all the disturbances of their system, and on other systems have been reported to be a higher percentage yet. In comparison with these ground current quenching devices the most up-to-date high speed protective relay equipments only will disconnect from the system by breaker operation the faulty section before any damage from power arc could be caused on the line conductor. The former bring about the self-clearing of the line-to-ground faults without any breaker action whereas relays cause tripping of the faulty circuit boundary breakers.

In view of the high percentage of disturbances which are being forestalled by Petersen coils one may speculate if such an equipment is not to be preferred to a second circuit on a transmission line, in case the second circuit is primarily chosen as reserve against interruptions on the first. Without knowing the exact cost of a Petersen coil it is safe to say that this will amount to a small fraction of that of a second circuit even if this is carried on a common tower. Labor costs are an important item on a transmission line construction and these constitute a higher proportion in America due to normally higher wages all around than those in Europe which even increases the economic value of the Petersen coil hereabouts.

Regarding the clearance of permanent ground faults, the authors seem in disagreement with the experiences obtained on the German systems, where it is said that the line can remain in service in presence of a sustained ground and permits exchange of insulators many hours after ground occurrence. However, the objections to a permanent ground on the 140-kv system in Michigan may be primarily due to corona currents which naturally are less felt on voltage systems of 110 kv or lower upon which German engineers base their conclusions.

The Petersen coil application may not be as desirable on an extensive utility transmission line network with generating stations at various points, as on straight transmission line from a remote hydroelectric station to a consumer step-down station of an industrial plant or domestic service. The recent transmission line system of the Nippigon-Fort Alexander power developments by the Ontario Hydro-Electric Commission has adopted metallic connections only on the low voltage side of both the step-up and step-down transformers, omitting any high voltage breakers. If such a system can be considered a pointer for future system designs, the application of Petersen coils is simplified, inasmuch as the main bug-a-bear of tuning in of the coil can be calculated without complications from complex high voltage line interconnections, and field adjustments will be reduced to a minimum.

In conclusion be it stated that the foregoing remarks are based upon the following papers by German engineers:

1. Petersen Ground Coil, Dr. Ruedenber, *Elec. World*, Nov. 30, 1930.

2. Selective Erfassung von Erd-und Deppelerdschloss, Dr. Kesselring.

3. Erdschloss und seine Bekaempfung, G. Oberdorfer. 1930.

4. Nippagon-Fort Alexander Power Development, Dr. Gaby. Engg. Inst. of Canada, 1931.

Paul R. Sidler: First; The authors speak of "Petersen coil" throughout the paper. It is quite true that Dr. Petersen has played a prominent part in this field, but it must be noted that his extinction coil, as originally conceived and applied, was based upon the assumption that the resulting fault current, after connecting the coil to the neutral, *must* be zero—this, of course, when neglecting loss-currents due to conductance and corona. This is the ideal operating condition for perfectly symmetrical networks.

In practice, however, there will always be certain differences in the capacitance of the 3 phases of a system to ground which cause an asymmetry-voltage between neutral and ground when connecting an extinction coil. This voltage produces a current through the coil which in turn causes a voltage difference across it. The value of this asymmetry-voltage depends therefore upon the inductance of the coil and it can be shown that it reaches a maximum value when the coil is completely tuned; i. e., when the inductance of the coil is exactly the same in value, but opposite in direction, to the capacitance to ground. It is obvious that with a larger

asymmetry-voltage the permanent losses during normal service are bigger.

This disadvantage of the Petersen coil can be eliminated by incomplete tuning, where the vectorial sum of inductance and capacitance is not zero, but leaves a small difference. This small residual voltage does not affect the usefulness of the coil for eliminating phase-to-ground faults. It is precisely this idea which has been incorporated by Julius Jonas (of Brown, Boveri & Co.) as early as 1918 in the so-called "dissonance extinction coils," as opposed to the resonance coils of Dr. Petersen. It would therefore be desirable not to speak of Petersen coils when referring to such devices in general, but to call them extinction or extinguishing coils.

As has been mentioned in the paper the question of saturation plays an important part in this connection. This diagram (Fig. 1) shows the influence of the tuning of coils with different saturation on the asymmetry-voltage in normal service. Curve 1 represents the asymmetry-voltage of the system under consideration. *A*, *B*, and *C* are the magnetizing curves of various extinction coils:

A = a coil unsaturated with normal operating voltage, tuned for resonance
B = a heavily saturated coil, tuned for resonance at normal phase voltage
C = a dissonance-tuned coil with small saturation and slight positive tuning

Positive and negative tuning is understood to mean a value of the coil inductance, in excess or below, respectively, of the value of the capacitance to ground. It appears from this diagram that resonance or Petersen coils cause high asymmetry-voltages with corresponding permanent losses and have no stable operating point when saturated. The dissonance coil produces a small asymmetry-voltage and has one operating point only.

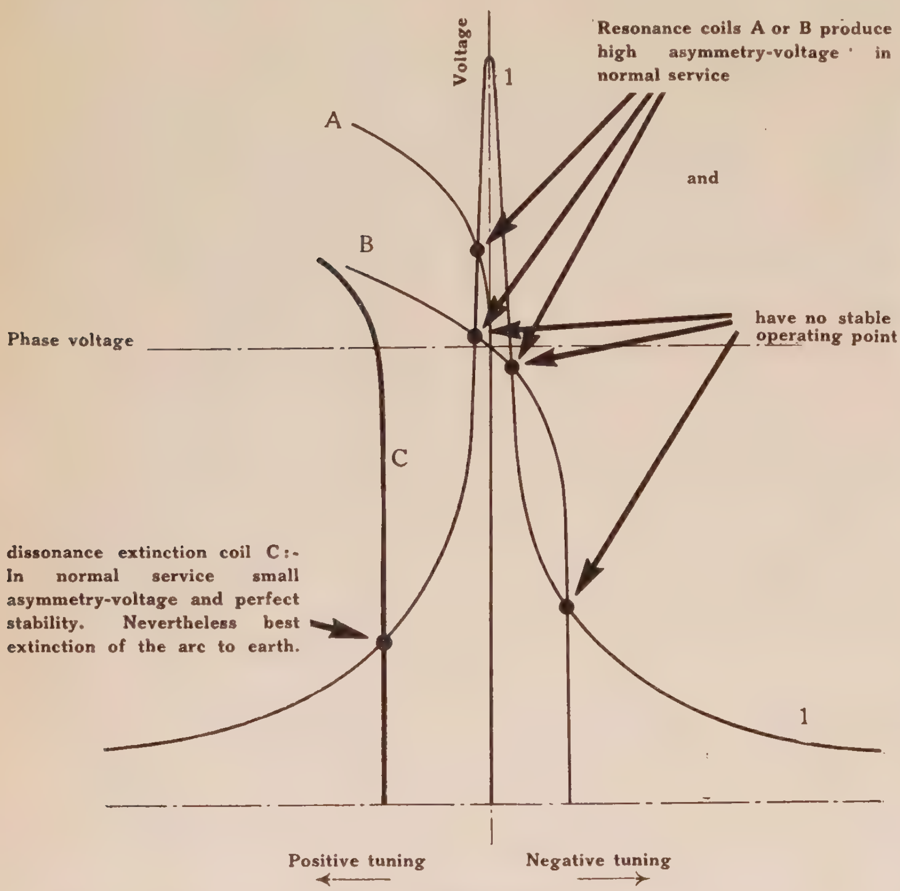


Fig. 1. Influence of tuning

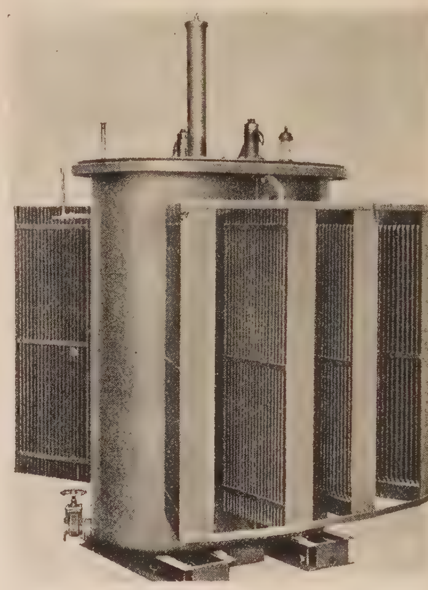


Fig. 6. Dissonance extinction coil, 2,320 kva during 2 hr, for protecting a 125-kv network

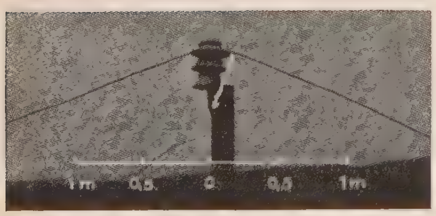


Fig. 2. Arc to earth with the extinction tuned for + 23 per cent

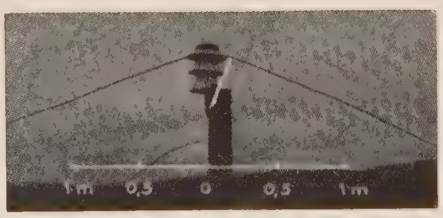


Fig. 3. Arc to earth with resonance tuning


Fig. 4. Arc to earth with the extinction coil tuned for — 20 per cent

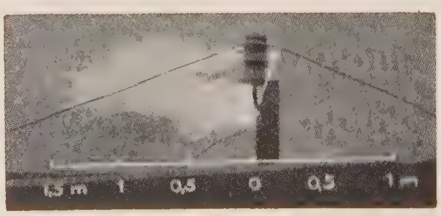


Fig. 5. Arc to earth with the extinction coil tuned for — 45 per cent

In Figs. 2–5 are shown arcs to ground with different tuning of an extinction coil, these pictures having been obtained during extensive tests in a 50-kv network. In Fig. 3 the coil is tuned for resonance, in Fig. 2 it has a positive tuning of 23 per cent, and in Fig. 4 a negative tuning of 20 per cent. No difference can be observed in the arc. Only with the negative tuning of 45 per cent, as shown in Fig. 5, the extinguishing effect of the coil is no longer satisfactory.

Second; On p. 64 of the paper it is stated that extinction coils have come to be standard practice in Germany. While this is true, it must not be concluded that Germany is the only country where they have been adopted to a considerable degree. We can name numerous installations of dissonance extinction coils in a great many countries:

20 are, for instance, in operation in Spain
8 in Denmark
14 in Poland
5 in Sweden
10 in the Dutch East Indies
and even far off China has 6 installations of this kind

Third; In the lower left corner of p. 70 appears the remark that Petersen coils can be effective only for clearing momentary faults. Again this is true for the 2 coils considered in the paper, which are rated for 10-

min operation only. With such a short time rating the most valuable characteristic of an extinction coil is lost, which consists precisely in the possibility of continuing the operation of the network with an existing phase-to-ground fault and without appreciable losses. Of course, such an operation is not to be continued indefinitely, but at least for a length of time sufficient to locate the fault and possibly remove its causes. For this reason extinction coils are usually rated for several hours' operation, 2 hr being considered adequate for a majority of cases.

In Fig. 6 is shown a dissonance extinction coil, rated for 2,300 kva during 2 hr for a protection of a 125-kv network in Eastern Europe.

Lightning Measured on 4-Kv Overhead Circuits

Discussion of a paper by Herman Halperin and K. B. McEachron published in the January 1934 issue, p. 33–7, and presented for oral discussion at the protective devices session of the winter convention, New York, N. Y., Jan. 23, 1934.

H. N. Ekvall: The results of this investigation supplement and lend support to conclusions arrived at previously through investigations of fuse blowings and transformer failures. These data, when combined, give a composite picture which should be of much value in the design of transformers, lightning arresters, etc., and also in correcting existing lightning trouble conditions through more effective distribution and application of lightning arresters.

Of particular interest to us is the similarity of operating experience in Chicago and Philadelphia. We concur for example in: (*a*) the apparently small amount of trouble from direct strokes, (*b*) less tendency for trouble on urban than suburban circuits, and (*c*) the decided reduction in trouble by use of the interconnection. I should like to comment briefly on the last of these.

Operating experience with the interconnection on over 1,300 transformers on the 2,300-volt 2-phase 3-wire ungrounded system in Philadelphia during the unusually severe lightning season of 1933 indicated a 75 per cent lower rate of trouble on transformers with the interconnection than on those without it. Also, all sizes and ages of transformers were benefited by its use. It was further disclosed that use of the interconnection did not augment trouble on customers' premises as indicated by analyses of meter troubles and house fuse blowings. This experience is comparable to that in Chicago in which use of the interconnection reduced trouble about 65 per cent and caused no adverse condition on customers' premises.

C. Francis Harding: The authors have not only made available to the profession through the Institute the possible economies of their studies over a period of years by means of statistical and check test analysis, but they have demonstrated the favorable results of a method of analytical attack upon an empirical problem which might well be followed in other branches of the profession.

After having reported in 3 Institute papers by D. W. Roper the results of a statistical analysis of lightning arrester operation and transformer failures in several sections of Chicago over a period of years it seemed probable that the interconnection of the secondary grounded neutral with the primary arrester ground might prove to be an additional protective device which could be cheaply installed and yet which seemed to have no objectionable features. To prove the efficacy of this interconnection and its lack of hazard to equipment or consumer by means of trial installations in the field was found to be too expensive, too long delayed and possibly associated with some risk.

An extensive laboratory research and experimental line investigation, under the auspices of the Utilities Research Commission of Chicago, was therefore undertaken at Purdue University by means of a surge generator and cathode ray oscillograph. The favorable results of such an interconnection and its lack of hazard were reported by Sprague and Harding in the papers referred to as Nos. 4 and 5 in this bibliography. It is therefore particularly gratifying to the speaker to find that the conclusions from laboratory and experimental line tests have been borne out in the field check tests reported in this paper.

In many other comparable cases such a carefully planned sequence of initial statistical studies, laboratory research and field check tests following the adoption of a new engineering principle worked out in the laboratory has not been adopted with one of the 3 following results:

(*a*) A new project has never been adopted, to the mutual disadvantage of the consumer, the public utility and the manufacturer, or
(*b*) Expensive and none too accurate statistical analyses have been exclusively depended upon, often with unfavorable results, or
(*c*) Competitors or other corporations with more progressive policies and foresight, but with less claim upon the original improvement, have subsequently undertaken the new development to their ultimate credit but with delayed value and unnecessary expense to the public.

This series of papers should, therefore, have a marked educational and illustrative value, looking toward the encouragement of research in practical engineering problems which may be undertaken in unbiased university laboratories whose results may be disclosed to the advantage of the profession and the public through the agency of the Institute.

D. D. MacCarthy: The data in the paper by Herman Halperin and K. B. McEachron which deals with voltages measured at distribution transformers is of great interest. It shows that the protection obtained with interconnection is much superior to that obtained with the old method. If the resistance of arrester grounds were not low in Chicago (97 per cent less than 25 ohms) the difference between the 2 methods would have been greater. This was shown in the McEachron-Saxon paper and the accompanying discussion. It should be noted when comparing the results of the 2 methods of protection, as shown in Table III, that the 5 line to ground voltages averaged for the interconnection are 12 kv more than for the standard, so that the incident surges must have been more severe. In spite of this, the voltage between the transformer windings is much less where interconnection is used.

The paper states that voltages of 30 and 37 kv were measured across the secondary leads of the transformers. The existence of such voltages must be very short. The insulation in the conduit of the customer's lead-in will spark at about 4 kv, as was stated in the McEachron-Saxon paper. Since the distance between the transformer and nearest lead-in is small, the effect of this breakdown will be to reduce the magnitude and duration of the voltage across the transformer secondary.

The paper states that the highest voltage recorded at an open end of a primary main was 205 kv and that the studies of D. W. Roper show that transformers installed within 100 ft of the end of a line have a 20 per cent lower rate of failure than other transformers. It may be incorrect to conclude on the basis of the data presented in this paper, that the voltage at the end of distribution circuits is not appreciably above the average. In Fig. 2 of the paper is shown an arrester between phase *B* and ground at the transformer and the recorder on the open end to be also on phase *B* 325 ft away from the transformer. The arrester at the transformer may have had a considerable effect in reducing the voltage at the open end. In the present study there were only 2 installations of this type, the next highest voltage measured at another installation was 158 kv, the lower rate of failure of transformers located near open ends may be due to the lower number of feet of exposure of the primary.

It is stated that Fig. 6, the plot of the profiles of the voltages measured on the long circuits, may represent distribution of the bound charge. Before making this conclusion it should be noted that the voltage at one end of the circuit is limited by an arrester which modifies the shape of the profile. The effect which the arrester has at points on the line other than its location depends upon the wave front of the surge or the rate of release of bound charge. It is seen from Fig. 6 that the voltage is also low at the end of the line opposite to the arrester. It would be of interest to know if this is due to the presence of branch circuits, other arresters, or what the cause may be.

Control of Distance Relay Potential Connections

Discussion of a paper by A. R. van C. Warrington published in the January 1934 issue, p. 206–13, and presented for oral discussion at the protective devices session of the winter convention, New York, N. Y., Jan. 23, 1934.

E. E. George: A. R. van C. Warrington has presented a most comprehensive view of the subject of "Relay Potential Connections." The Tennessee Electric Power Company has used switching of both potential and current connections with a reactance type of distance relay which was manufactured in Europe. The operating features of this switching arrangement were designed to

take care of special conditions and would probably be satisfactory on a system with lines protected entirely by relays of this same type and design. We have discontinued the current and potential switching features on most of these relays.

We believe that the switching arrangements shown in Mr. Warrington's paper are intended for use with potential transformers instead of bushing potential devices or other substitutes. Most distance relays now on the market will cause an appreciable change in the voltampere burden of the current circuits, potential circuits, or both, when different portions of the relays operate. Bushing potential devices have been found to have objectionable errors in ratio and phase angle when subjected to changes in burden, particularly at the low voltages encountered during short-circuit conditions. It is our opinion that any changes in burden should preferably be made in the potential circuit since one set of potential transformers on the station bus with bushing current transformers on the outgoing lines will usually be more economical and certainly more reliable than bushing potential devices and wound type current transformers on each line. We also prefer potential circuit switching instead of current circuit switching for other reasons as brought out by Mr. Warrington.

We wonder if due weight has been given to the fact that the nature of many faults may change even before high speed relays and breakers have a chance to operate. It is necessary for the switching arrangement to be exceedingly reliable in operation to take care of such conditions.

Up to the present time we have preferred to confine the use of added devices to those desirable for making 1 set of 3 distance relays extremely accurate under all faults involving 2 or more phases with or without ground current (such as the use of wye-delta auxiliary current transformers) and to depend on current directional ground relays for protection against single phase to ground short circuits. Probably the circuit shown in Fig. 3 using one distance relay for the protection of single phase to ground short circuits would be advantageous with or without a current directional ground relay, particularly in those cases where it is impractical to coördinate substation switching and grounding capacity, so as to provide fast and accurate relaying with inverse time overcurrent ground relays. Probably the use of potential switching arrangements will be influenced greatly by the cost and reliability of the various switching devices.

J. H. Neher: While the many advantages to be gained by the use of distance relay protection are almost self-evident, this type of protection is inherently more expensive, more complicated, and requires more panel space than other simpler forms of protection. It is therefore interesting to a relay engineer to find a manufacturer sponsoring some system whereby any or all of these factors may be reduced.

The old theory that the more relays you have the better off you are, because there is less probability that a given relay failing to operate can result disastrously, has very little engineering justification, and in these days no economic justification.

In the most complete distance relay protection the relay of one phase effectively backs up the relay on another phase, only in the case of 3-phase faults, which are rare, and practically no back-up is afforded in the case of the more frequent types of faults. Even at that, the back-up is confined to one link of a chain extending from the plates of the control battery to the contacts of the circuit breaker, and in which, I venture to say, the primary relay is not necessarily the weakest link.

If the potential selector system can be made as reliable as the relay itself, and the combination results in a simplified or less costly system which will perform the duties of the conventional multi-relay system in a satisfactory manner, it would seem hard to justify the multi-relay system.

In Fig. 2 of the paper, the effect of delta-connected current transformers is obtained from the wye connection by the use of a double current winding relay. I should like to point out that a single current winding relay may be used in this arrangement, provided a center tapped autotransformer is connected between the *A* and *C* phase current leads, with the center tap connected to the common return. The current coil of the relay is connected between the center tap and one end of the autotransformer. The operating conditions are identical with those given in Table II.

All of the systems presented are based upon the assumption that the potential supply to the directional element is obtained from the same phase as the potential supply to the distance element. Relays requiring different phases for these supplies will require separate switching for the 2 elements. Independent switching, while adding to the complexity of the arrangement, permits the application of overvoltage to the directional element potential coil during the duration of the short circuit. In this manner, the directional element may be made more sensitive than is possible in the conventional multi-relay scheme. In fact, in the case of close-in 3-phase faults, where high speed operation is most essential from a stability standpoint, the net time of operation may be decreased despite the addition of a transfer relay which must operate before the distance relay proper can start to function.

In many of the systems shown, the potential circuits of the distance elements are normally open. Since the modern high-speed distance relay is not directional controlled, this means that normally the contacts of the distance elements are closed; and when a fault which should not cause instantaneous tripping occurs, a race must take place between the distance element on opening and the directional element on closing. This race must be won by the distance element. Granted that the distance element has the advantage of being circuit opening, and that this same race can take place under certain circumstances with the conventional relay set-up, nevertheless it is something which should be avoided whenever possible. In certain cases, it is possible to arrange the potential selector system of the distance element so that this element is normally energized between phases and then is switched to ground or to another phase, cutting the series impedance out or in as may be required without opening the circuit.

In the discussion of Fig. 5, the author explains that the system must not be switched to wye voltage in case of a double ground fault, and introduces a slight time delay in the transfer relay to prevent this. I should like to point out that should a double ground fault develop from a single ground fault after the transfer to wye voltage had taken place, incorrect operation might occur before the system can transfer back to delta voltage.

Automatic Reclosing of Oil Circuit Breakers

Discussion of a paper by A. E. Anderson published in the January 1934 issue, p. 48–53, and presented for oral discussion at the protective devices session of the winter convention, New York, N. Y., Jan. 23, 1934.

E. E. George: In Table I is a tabulation showing the instantaneous reclosing record of The Tennessee Electric Power Company during 1933. The percentages are based on about 1,500 operations using a cycle of zero sec—120 sec—lockout in most cases. We agree with A. E. Anderson that the third reclosure is desirable and we are changing to a cycle of zero sec—15 sec—120 sec—lockout, especially on the lower voltage circuits.

Table I

	Breaker Remained Closed		
Reclosure	Attended Substations	Non-Attended Substations	Total
First	61.2%	93.2%	73.5%
Second	23.5%	2.8%	15.6%
Lockout	15.3%	4.0%	10.9%

The differences in the performance records of the fully attended substations are noteworthy. For records at the nonattended substations, we use oil circuit breaker counter readings taken on monthly inspection trips and whatever information is available as to interruptions. We are inclined to question reclosing records which depend upon the public or upon nonoperating employees for data on actual interruptions. This company has just developed an inexpensive method of mounting an operation counter inside of the various reclosing relays which records the total revolutions of the timer drum. Absolute accuracy should be feasible from the readings of this counter and the counter on the oil circuit breaker in the case of a 2-reclosure cycle and also in the case of a 3-reclosure cycle if the number of breaker operations between inspection trips is relatively small. These counters are now being installed at all nonattended substations.

It has been our experience that synchronous motors will frequently pull into step after a total interruption of 40 cycles without the use of any field removing devices. The presence of large synchronous motors, not too heavily loaded, at an industrial plant has been found to be advantageous in that voltage on induction motors in the plant will be maintained to a certain extent by the synchronous motors and instantaneous undervoltage releases on induction motors will be prevented from operating during the reclosing cycle.

H. A. P. Langstaff: In A. E. Anderson's paper it is stated that practically all applications of automatically reclosing oil circuit breakers have been on stub or radial feeders and that the discussion is confined to this type of application. The West Penn Power Company has a total of 170 applications, 93 of which are on stub feeders and 77 on interconnected lines. This latter group is composed of 22-kv, 25-kv, and 44-kv, 3-phase 60-cycle circuits; of this latter group, 33 reclose only when the line is energized from the other end. From this it is evident that about 45 per cent of our total applications are on interconnected circuits.

Our records over a 3-year period show about the same number of total operations per year, but the percentage of lockouts is gradually increasing as follows: 6 per cent in 1931, 13 per cent in 1932, and approximately 15 per cent in 1933. The percentage increase may be slightly affected by a reduction from 3 to 2 reclosures, which indicates to us that further consideration should be given to the value of the third reclosure. At present 7 per cent of our total applications are adjusted for 1 reclosure; 43 per cent, 2 reclosures; and 50 per cent, 3 reclosures. Time intervals between reclosures vary from immediate to one minute. Six per cent of our total applications are adjusted for immediate initial reclosure. Our experience with these applications thus far has been quite successful and this percentage will be increased. Careful study is made before changing to the immediate reclosure. The design of quite a number of our reclosing relays is such that the time may be varied from instantaneous to several minutes if desired, which, of course, permits universal application.

An analysis of reclosing operations from a delta versus grounded distribution circuit point of view shows about double the number of lockouts for solidly grounded distribution systems as compared with delta systems. Proper fuse and relay coördination is quite necessary for reclosing performance and may reduce the number of lockouts resulting from short circuits.

In general, I believe breaker designs should tend toward a time reduction in operating cycles. Application of immediate reclosures or reduction in time for reclosures has not increased maintenance on our oil circuit breakers. In only a limited number of cases have we found it necessary to modify existing protective relays to meet the new reclosing time intervals. We found it necessary to change cascaded relay settings to allow for shorter reclosing periods. A timing mechanism eliminating the use of any revolving parts is desirable. All contacting mechanisms should be as rugged and positive as economically possible. I believe there is a decided advantage in having the third reclosure in conventional design when practically no additional expense or complication is added.

About a year ago I considered the application of automatic reclosing equipment in attended stations but our analysis proved that the very limited number of distribution circuit outages per year—less than 2 per circuit—and the few seconds reduction in time of circuit reclosing would not warrant the necessary expenditure for timing relays and control circuit modifications. I might add that the territory covered is not of a metropolitan type.

Counterpoises for Transmission Lines

Discussion of a paper by Charles L. G. Fortescue published in the December 1933 issue, p. 908–17, and presented for oral discussion at the power transmission session of the winter convention, New York, N. Y., Jan. 24, 1934.

L. V. Bewley: Doctor Fortescue's analysis of the counterpoise problem is characterized by the following assumptions and arbitrary factors:

1. A "true" ground plane, common to both the electrostatic and the electromagnetic fields, is taken at a depth varying with the soil resistivity.
2. A factor K, assumed to be between 4 and 16, is introduced to account for the permittivity and leakage of the soil.
3. The surge on the counterpoise is "conceived to consist of 2 parts, one of which moves with the velocity of light and is proportional to s (an empirical factor less than unity) and a second portion moving with a velocity $1/\sqrt{K}$ that of light and whose magnitude is proportional to $(\sqrt{K} - s)$."
4. The s part of the surge on the counterpoise is assumed to have a mutual surge impedance proportional to unity, while that of the $(\sqrt{K} - s)$ part is assumed to be proportional to $(1/\sqrt{K})$.
5. The fraction m of the total ground current is calculated neglecting the effect of the coupling between ground wire and counterpoise.
6. During the transient the surge impedance of the counterpoise is assumed to remain constant.
7. The lightning stroke itself is assumed to have a surge impedance of 200 ohms.

From these premises Doctor Fortescue has built up a theory taking into account surge impedance effects, coupling, and successive reflections up and down the tower. The most remarkable conclusion of his analysis is the very large effective coupling with the line wire. Thus, according to his Table II, at the instant of maximum voltage across the insulators the coupling is 73 per cent, and it subsequently reaches 81.5 per cent.

In an article to appear in the February 1934 issue of the *General Electric Review* I have applied the multiconductor multivelocity theory of traveling waves to the analysis of the counterpoise. In general, I agree with Doctor Fortescue's conclusions, except that according to my calculations:

1. The effective coupling is very much less than he finds, and therefore there is not nearly so much advantage in favor of the parallel counterpoise. For example, with a single counterpoise the coupling is only 44 per cent.
2. There is no practical need to complicate the analysis and increase the labor of computations by taking the successive reflections in the tower into account. I find that only the first 3 or 4 reflections are appreciable, and these will subside by the time that the lightning surge reaches its crest (assuming a front of one microsecond or more). Taking reflections into account makes less than 10 per cent difference in the maximum voltage, but for comparative computations this certainly does not warrant the great increase in work.
3. The surges on the ground wire, line conductor, and counterpoise are, respectively:

$$\left.\begin{aligned} e_1 &= 0.558\,E_0\,(0.78) + 0.220\,E_0\,(0.33) \\ &\quad + 0.221\,E_0\,(0.71) \\ e_2 &= 0.472\,E_0\,(0.78) + 0.254\,E_0\,(0.33) \\ &\quad - 0.289\,E_0\,(0.71) \\ e_3 &= -0.033\,E_0\,(0.78) + 1.028\,E_0\,(0.33) \\ &\quad + 0.006\,E_0\,(0.71) \end{aligned}\right\} \quad (1)$$

where the figures in parentheses are the velocities relative to that of light. Thus no component wave on the system travels at the velocity of light; and moreover, the surge on the counterpoise is essentially a low velocity wave traveling at about 1/3 the velocity of light.

These discrepancies result principally from the differences in our respective concepts of the rôle of the ground. Doctor Fortescue uses a single equivalent ground plane, and therefore calculates both electrostatic and electromagnetic coupling between the counterpoise and the overhead conductors. I hold that the ground is essentially at zero potential with respect to the electrostatic field, and consequently there can be no electrostatic induction between conductors on or in the ground and overhead conductors. Therefore, I calculate a much lower coupling, definite reactions from the isolated line conductors, and consequent multivelocity waves. My multivelocity components are given automatically by the multivelocity theory, and no arbitrary assumptions need be introduced relating to their several magnitudes and velocities. While both Doctor Fortescue and I make an analysis on the basis of a counterpoise of constant surge impedance, it must not be forgotten that the actual surge impedance may decrease considerably by the time the lightning crest is reached. This would result in more current in the counterpoise and greater coupling with the line conductor. I bring this point up because tests may reveal a greater coupling than an analysis based on the initial surge impedance assumed to remain constant. In my article there is an equation and a test curve showing how the surge impedance varies with time.

I believe that the surge impedance of a lightning stroke is nearer 400 ohms than 200 ohms. (See "The Lightning Stroke" in the December 1933 issue of the *General Electric Review*.)

Doctor Fortescue introduces geometric mean radii (G.M.R.) in calculating his surge self impedances. I do not understand by what labor-saving process he arrives at G.M.R. in this problem. Considering 2 ground wires in parallel in the same horizontal plane, carrying equal voltage and current waves, the heights of conductors being h for the magnetic and H for the electrostatic fields, separation s, actual radii r, and corona radii R, the surge impedance on the basis of multivelocity theory is

$$\begin{aligned} Z &= \sqrt{(L_{11} + L_{12})(P_{11} + P_{12})} \\ &= 60\sqrt{\log 2\sqrt{\frac{ha}{rs}}\,\log 2\sqrt{\frac{HA}{Rs}}} \end{aligned} \quad (2)$$

where

$$a = \sqrt{4h^2 + s^2} \quad \text{and} \quad A = \sqrt{4H^2 + s^2}$$

Now even if $h = H$, as Doctor Fortescue assumed, this becomes

$$\begin{aligned} Z &= 60\sqrt{\log 2\sqrt{\frac{ha}{rs}}\,\log 2\sqrt{\frac{ha}{Rs}}} \\ &\cong 60\sqrt{\log\frac{2h}{\sqrt{rs}}\,\log\frac{2h}{\sqrt{Rs}}} \end{aligned} \quad (3)$$

which is not algebraically convertible to the form given by Doctor Fortescue,

$$Z = 60\,\log\left(\frac{2h}{\text{G.M.R.}}\right) \quad (4)$$

Incidentally the equations of conventional traveling wave theory fall down completely in this case, for according to them, since $i_1 = i_2$

$$e_1 = Z_{11}\, i_1 + Z_{12}\, i_2 = \frac{Z_{11} + Z_{12}}{2}\,(2i_1) \qquad (5)$$

and the surge impedance would be

$$Z = \frac{Z_{11} + Z_{12}}{2} = 30$$

$$\left\{\sqrt{\log\left(\frac{2h}{r}\right)\log\left(\frac{2h}{R}\right)} + \log\left(\frac{2h}{s}\right)\right\} \quad (6)$$

The trouble is that as soon as we assume $r \mp R$ or $h \mp H$, the differential equations are no longer uniquely satisfied by single-velocity waves, and so eq 5 ceases to be a complete description of the voltage and current relationships. Of course, if we put $r = R$ and $h = H$, eqs 2, 3, and 6 all become equal to

$$Z = 60 \log \frac{2h}{\sqrt{rs}}$$

which is now agreeable with eq 4. Nevertheless, while eqs 5 and 6 are algebraically different, they give numerical values which differ but little. For example, if $h = 200$ ft, $r = 0.375$ in., $R = 12$ in., and $s = 30$ ft, the surge impedances calculated by eqs 3 and 6 are 304.5 and 303, respectively.

J. E. Clem: Some time ago we had under consideration a proposed design of a transmission line using the buried parallel counterpoise in addition to the customary overhead ground wires. The question arose as to how much additional loss at the operating frequency might be occasioned by the use of the buried counterpoise extending the entire length between the towers. In view of the fact that some fears had been entertained that the additional losses might be relatively great, exact calculations were made and these indicated that the extra loss was practically negligible.

Calculations were made on a horizontal line with an average height of $58^7/_8$ ft and with a conductor spacing of approximately $28^1/_4$ ft. The overhead ground wires were located in a plane approximately $25^1/_8$ ft above the plane of the line conductors and were spaced $42^1/_4$ ft. The buried counterpoise wires were located directly underneath the overhead ground wires and were assumed to be about 2 ft under ground. The line conductors had a diameter of 1.14 in. and a resistance of 0.117 ohm per mile. The overhead ground wires had a diameter of 0.714 in. and a resistance of 0.364 ohm per mile. The buried counterpoise had a diameter of 0.419 in. and a resistance of 0.433 ohm per mile. If the line conductors are numbered 1, 2, 3, from left to right; the overhead ground wires numbered 4 and 5 from left to right; and the buried counterpoise wires 6 and 7 from left to right, the following distribution of current is obtained:

$$\frac{I_4}{I_1} = 0.0945 \qquad \frac{I_6}{I_1} = 0.0228$$

$$\frac{I_5}{I_1} = 0.0745 \qquad \frac{I_7}{I_1} = 0.0222$$

From these figures the total loss in all the ground wires is found to be approximately 1.6 per cent of the total loss in the line.

It is rather surprising to note that the current in the overhead ground wires is not evenly divided. This at first was taken as indicating that there might be some mistake in the calculations. However, further study brought out the fact that the unequal division of current was reasonable and could be altered to give the greater current in the other ground wire by changing the phase sequence of the line conductors.

Bradley Cozzens: At the present stage of the art, to say that some particular method of computation of lightning phenomena is or is not correct should meet with severe criticism; for we yet are not certain of the mechanism of lightning, the potential that may be developed, the currents that may occur in a discharge, or the impedance of the streamer path, though all these values have been estimated with a greater or less degree of authenticity. Therefore, the following discussion is given to call attention to some other methods of computation and a different viewpoint, rather than as an attempt to disprove the values as given.

Doctor Fortescue presents an analysis of the counterpoise methods as used in eastern installations, but his mathematical analysis seems to be applied directly to the counterpoise system as scheduled for the transmission line of the Bureau of Power and Light from Boulder Dam to Los Angeles. Though the method described by Doctor Fortescue was considered in the studies made prior to determining upon the use of a counterpoise, methods substantially different from those presented in this paper were used in the computation.

Doctor Fortescue draws the conclusion (ELECTRICAL ENGINEERING, December 1933, p. 910) that the radial counterpoise gives lower surge impedance than the continuous type of buried counterpoise. It is believed that from previous papers of Doctor Fortescue, and from values of voltage that may appear on the counterpoise as given later in this paper, that the value of a corona radius of 0.166 ft is small. Using this value however, and the more liberal value of 130 ft for the separation of the counterpoise wires, the equivalent G.M.R. (geometric mean radius) of the 2 counterpoise wires would be increased to 4.65 ft, and for the first case (namely, the 50-ft ground plane) the surge impedance of the parallel counterpoise will be $186.6/\sqrt{K}$. ohms. This is lower than the value of surge impedance for the radial counterpoise. However, where the ground level is taken as 200 ft below the surface, the value of the surge impedance for the continuous parallel counterpoise becomes $258/\sqrt{K}$ ohms which is slightly higher than the value of surge impedance for the radial counterpoise. There is thus little difference between the computed values for the 2 systems. There are, however, 2 other very important facts that determine effectiveness of the 2 systems:

1. Tests have shown that radial counterpoises or short sections of buried cable used in dry soil have appreciable voltage reflected from the ends of the wires, thus making the effective surge impedance much greater than the computed surge impedance; whereas for the continuous counterpoise, there is no positive reflected wave, and consequently no building up of potential at the base of the tower.

2. It is known that where the charge builds up as slowly as in clouds, the charges of opposite polarity collect on or close to the surface of the earth, even though the soil is of high resistance, rather than at the theoretical ground plane. This is necessarily true or else rocks and mountain tops could not produce the corona so often observed. It is these charges on the surface of the earth that the counterpoise collects when lightning terminates on a tower, and to which the counterpoise capacitance should be figured in determining its surge impedance. The *inductance* of the counterpoise may be computed with respect to the cloud as the return circuit, though this value is practically the same as that of an isolated wire. Also close to the tower base there is little inductance due to the wires leaving the base in opposite directions, as mentioned by Doctor Fortescue. Though this method of computing the surge impedance of the counterpoise is a little more complicated than that given in the paper, it is felt to be more accurate and to more perfectly represent the action of the lightning discharge.

The values of K for the effective dielectric constant of the soil were checked independently by computing the value of surge impedance by the aforementioned method for the lengths of buried conductor used in the test of Brune and Eaton (A.I.E.E. TRANS., v. 50, p. 1132). It was found necessary to use a dielectric constant or soil factor of between 8 and 10 to make the computed results check the test values.

The Knob Hill experience is of course familiar to all following lightning experience records. It is understood, however, that only one counterpoise wire is used per circuit on this installation. It is felt that even though this is a high rock formation, the frequent rains in that area probably produce much more moisture in the rock seams and interstices of the rock than might be found in the desert area through which the Boulder Dam transmission line of the City of Los Angeles will have to pass. At present, one very important part of lightning information that is lacking is the effect of soil and soil moisture on the action of the counterpoise.

In the study of the lightning protection for the Boulder Dam transmission lines, it was felt that the attenuation in the counterpoise was too rapid to consider it having an appreciable part of the lightning potential impressed upon it for any measurable distance from the tower base. Further, the speed of propagation of the voltage wave in the counterpoise has been found to be about $^1/_3$ of that in an air line, both by computation and by the tests of Messrs. Brune and Eaton. Thus at a short distance from the tower where a stroke might terminate, the potential of the counterpoise would lag behind that of the ground wires. For the case of a stroke at midspan (1000-ft span) the potential of the counterpoise directly below it would require 2μsec to be changed by a wave traveling along the ground wire to a tower and returning on the counterpoise wire. It was thus much more conservative to assume that the counterpoise had sufficient conduction to maintain ground potential below the line, and that for the computation of its surge impedance that only a small part of the lightning potential would appear on the buried counterpoise. The coupling between the ground wires and line wire was thus computed on the more conservative basis using the effective ground plane as the surface of the earth, rather than the water table which might be at considerable depth.

On the Boulder Dam to Los Angeles transmission line, 4 counterpoise cables will be buried, 2 under each circuit, spaced 130 ft apart. The normal center line spacing between circuits is 265 ft. At each point where towers are adjacent, a buried cross tie will connect towers. Where possible, the counterpoise wires will be brought in from their normal spacing to each tower base at an angle of about 45 deg

and connections made to the tower. Thus the advantages of a "crow's foot" or radial counterpoise is obtained by the 4 continuous wires and the one cross tie leaving the tower base, while the wire being continuous prevents any positive reflections of voltage from open ends, or ends terminating in high impedance.

It is believed that Doctor Fortescue's new method of computing the effects of the counterpoise is too liberal, giving better protection than will be found in practice. If it does prove to be the correct analysis, however, the continuous counterpoise as installed on the Boulder Dam lines with other bases of installation will be willing to function as he predicts.

Stanton Hertz: This discussion deals with the treatment of diameters of overhead ground wires, as they might be affected by the system of calculation presented in Doctor Fortescue's paper. Those of us who will design and apply overhead ground wires in the future, and calculate the protective value of the over-all line designs, will wonder whether a new basis for selecting diameters of overhead ground wire will be caused when using the new formulas presented in this very valuable treatise.

Heretofore, the diameter of overhead ground wire to be used in each design (and hence the weight and cost of the ground wire) has generally been determined, not for reasons of the diameter's influence on the amount of electrical protection from lightning, but primarily to suit the physical and structural safety requirements. In other words, sag and tension and safety-factor conditions alone have generally caused the decision as to what diameter of material need be chosen for the ground wire. Is this method of determining diameter to be changed? It seems not.

The formulas in Doctor Fortescue's paper show that the enlarging of the diameter of a ground wire causes a very small and almost negligible improvement in the protective value of the line design. On the other hand, it is seen that an increase in diameter will increase the weight and cost approximately as the square of the diameter. A clear example of the added cost burden when increasing the diameter unnecessarily is shown by comparing a $^3/_8$-in. diameter with a $^5/_8$-in. diameter ground wire, assuming that $^3/_8$-in. is satisfactory structurally. The cost for a pair of $^3/_8$-in. ground wires on 100 miles of line may be about \$52,000, while for $^5/_8$-in. diameter of the same material the cost would be about \$132,000, an increase of about \$80,000 or about 150 per cent. On the other hand, the electrical protective value resulting from increasing the diameter from $^3/_8$ in. to $^5/_8$ in. is shown by these calculations to be very small, on the order of less than 5 per cent, possibly around 3 per cent, this depending on the design. Obviously it is not desirable to seek greater protective value through the enlargement of the diameter of ground wire, because of the resulting disproportionate increase in weight and cost. It is much more economical, when seeking greater protective value, to make changes in spacings or clearances, or by adding another insulator unit to the insulator strings.

The following figures on ground wire diameters in use in the United States have not heretofore been published, but might be of value for inclusion in a discussion of this paper. These figures are summarized from records of ground wires installed during the 10-yr period from 1923 to 1933, covering 339 transmission line installations of "Copperweld" overhead ground strand. They may therefore be said to be indicative of diameters used in recent and modern transmission line design. The mileage of strand in this summary is 5,680 miles. The average diameter of all these installations is almost exactly $^3/_8$-in. Over 95 per cent of the mileage is of diameter from $^5/_{16}$ in. to $^1/_2$ in., while the largest size used, $^5/_8$-in. diameter, constitutes only about 2 per cent of the total. The $^3/_8$-in. size alone is about 40 per cent of the total.

In the future use of the valuable calculations described in Doctor Fortescue's paper, it seems desirable to continue the practice of fixing the ground wire diameter entirely on the basis of sag and tension and safety-factor conditions; that is, to choose that diameter which may be strung somewhat tighter, at a less sag, than the power conductors, and have a slightly higher factor of safety than the power conductors over which it is to be strung.

Herman P. Miller, Jr.: A translation of the theory given by Doctor Fortescue into the language of the radio engineer might assist in studying the subject. A lightning discharge is similar to the spark discharge used in the old spark type of radio transmitters. Only one discharge occurs, instead of a series at periodic intervals, and this discharge is highly damped.

There appear to be a number of resonant circuits in the ground system of a transmission line which might be excited by such a discharge. There is the vertical loop formed by a span of the overhead ground wire, the towers at each end, and the so-called "ground plane." Another possibility is that the ground wire acts as a multiple tuned antenna with the towers serving as down-leads. In the latter case the ground system may be considered as a series of resonant circuits each of which includes $^1/_2$ span of ground wire on each side of a tower, the tower, and the ground plane connected to the base of the tower. The resonant frequency of such a circuit would be extremely high and would be governed by the tower height and spacing.

The effect of a lightning stroke would be to set up damped oscillations in such a circuit. The voltages resulting from these oscillations would depend upon the intensity of the stroke and the coupling with the resonant circuit furnished by the stroke path. Their duration would be determined by the damping of the circuit. To increase the damping, the effective capacitance of the circuit could be increased by bringing the ground plane up closer to the ground wire; the effective inductance could be decreased by using more or heavier conductors between the ground wire and the ground plane; or the effective resistance could be increased by inserting a noninductive resistance in the circuit at some point.

The potentials impressed on the transmission wires would depend mainly on the coupling between them and the resonant circuits. The coupling would be mainly capacitive and would be roughly proportional to the relative heights of the line wires and the ground wire above the ground plane. When the ground plane is somewhat below the level of the tower footings, these heights are more nearly the same than when the ground plane is raised by the use of counterpoise wires.

From this method of considering the subject it will be seen that the use of a counterpoise in a soil of poor conductivity decreases the excitation of a resonant tower circuit by decreasing the reactance of the stroke path. It increases the damping of the resonant circuit by increasing its effective capacitance, although a part of this increase is counterbalanced by the decrease due to lowered resistance. It also decreases the transient potentials on the line due to less coupling with the resonant circuit.

In studying a counterpoise on the above basis, some help might be obtained from the results obtained on radio antennas as given in various technical publications.

P. B. Stewart and F. E. Sanford: Operating experiences and records of the transmission and distribution circuits of the Union Gas & Electric Company in the territory around Cincinnati, Ohio, do not confirm the conclusion that ground resistance of protection or footings is the only factor to be considered in lightning protection. There is apparently some contributing factor, which has not been entirely explained, that would account for the wide differences of flashovers and operating troubles.

The theory of counterpoise effect advanced by Doctor Fortescue offers a valuable addition to protective considerations dealing, as it does, with the relation between voltages on different parts of the transmission lines, when lightning has struck. It may be still lacking an important factor of comparison, which is the frequency of lightning strokes in a given area. That is, there may be a direct relationship between the earth strata and the frequency which may help to explain the effect of counterpoise and other surge impedance reduction theories and methods.

Perhaps Mr. Fortescue has already considered the possibility of the influence of geophysical factors, which seem to us to offer one explanation for otherwise unexplainable differences in operation. A theory advanced by L. N. Bogoiavlensky (*Nature*, July 15, 1933) is that lightning follows a path of good air conductivity, which may be due to ionization from radioactive earth. This theory is supported by some authors on physics. A survey made in 10 regions in Russia by means of measuring the intensity of the penetrating earth radiations by an electrometer of special type, and by the method of electrical boring of Schlumberger, is the basis for this report. A direct correlation of the frequency of lightning discharges and curves of the intensities of the penetrating earth radiations shows that the highest frequency always corresponds to the place with increased intensity. A sharp pointed (or mountainous) profile of the layers of rock indicates a corresponding increase in the frequency over a smooth or even profile.

Since we have never taken measurements, we cannot confirm this theory, but it would to a considerable extent explain discrepan-

cies in the present theories. We have several examples that dispute the theory of ground resistance. Several years' experience on the 66-kv Columbia-Hartwell circuits show that no direct relation exists between flashovers and tower footing resistance. We have also plotted flashovers against elevation above sea level and find no explanation of the differences, from this standpoint.

Also, 2 33-kv lines of identical construction, operating over similar territory and with similar average ground resistance values, show 2 or 3 times the number of lightning faults for one line compared to the other one.

Another example with 33-kv lines directly disputes the theory. One line, which has many more lightning faults than a similarly constructed line, traverses low, level territory, and has low ground resistance, while the second line traverses a hilly and rocky country with high ground resistance.

A similar comparison on the 4-kv distribution system also disputes the theory of ground resistance. Two feeders of similar construction and exposure supply territories, one east, and one north of Elmwood Station. Of 13 cases of trouble in 2 years, 11 occurred in the east part, where the average ground resistance is 19.1 ohms. The average ground resistance in the other section was 65 ohms, and the number of transformers in the 2 areas is about equal. The average resistance of the driven grounds at locations where trouble occurred was, however, greater than the average for that area.

The practical benefit of counterpoises may be explained by an effective leveling of the earth strata from an electrical standpoint, as well as by the lowering of surge impedance or ground resistance.

R. D. Evans: (See p. 473.)

Corona Losses from Conductors of 1.4-In. Diameter

Discussion of a paper by Joseph S. Carroll, Bradley Cozzens, and Theo. M. Blakeslee, published in the December 1933 issue, p. 854–60, and presented for oral discussion at the power transmission session of the winter convention, New York, N. Y., Jan. 24, 1934.

C. Francis Harding: Having made corona tests almost continuously at Purdue University since 1912, at which time our first paper on the subject was presented before the Institute, I am naturally very much interested in the results of the tests on cables of the large sizes and spacings reported in this paper.

Unfortunately the tests of various types of cables were not carried on throughout the same range of temperature, barometric pressure, humidity, and rain conditions, nor were they all comparable from the standpoint of the 3-phase vs. single-phase operation. It would be more appropriate, of course, to compare such cables under identical long term test conditions.

Figure 1 indicates the wide range of temperature, barometric pressure, and humidity which obtained during the various tests. Although the critical corona forming potential is not reached for cables of this size at the normal operating voltage specified for this line, such corona potentials will, no doubt, exist throughout some portions of such a long line as that contemplated, particularly at the higher altitudes through which it must pass.

Assuming the line to be operating at the critical corona potential under the *average* conditions of temperature and barometric pressure which obtained during these tests, it is found by calculation that the losses during the tests conducted at the higher temperatures are of the order of 4 kw per mile of 3-phase line, while the effect of the altitude of 3,500 ft at which a portion of the line is to operate will account for a loss of 29 kw per mile. In other words, the conditions due to temperature changes during the various tests and the variation in barometric pressures to which the actual line will be subjected will produce losses in all types of cables many times the variations due to differences of design, thereby making such latter variations a negligible quantity since the highest losses at normal operating potentials are shown to be of the order of from 1 to 1.5 kw per mile and the difference between individual cable losses only a small fraction of that value.

Although adequate data are not available for a complete humidity-loss curve, it is generally recognized that there is some considerable variation in critical corona-forming potential and in the resultant corona loss with changing humidity. The wide variation of humidity of from 20 to 62 per cent under which these cables of different designs and makes were compared would certainly affect the corona losses even with no change of design. Although at first it appeared that variation in humidity had little to do with corona losses, the following more recent quotation from the able work of the late F. W. Peek is significant.

"Greater loss should be expected in corona measurements during fog, due to charge and discharge of water particles. This causes loss at lower voltages and has the effect of decreasing the corona point. While humidity has no effect upon the starting point of corona, an effect might be expected on the loss after the discharge had already started."

It is probable that more recent tests will establish a relation between humidity and the starting point of corona as well, which will account for much of the variation in the losses during these tests. An earlier paper by some of the authors of this paper also indicates that corona losses are somewhat dependent upon humidity. ("Corona Loss Measurements on a 220-Kv 60-Cycle 3-Phase Experimental Line," by J. S. Carroll, L. H. Brown, and D. P. Dinapoli, A.I.E.E. TRANS., v. 50, 1931, p. 36.)

Of course the comparative losses during rain and snow storms are of greater importance than the variation in fair weather losses resulting from the different designs of the cable surfaces. Although it was unfortunate that all cables could not have been tested under rain conditions in order that the more serious operating losses might have been determined, it is probable that those cables which have a completely closed tubular periphery such as Types *C* and *F*, as contrasted with the cables of stranded exterior, will tend to hold water longer after a storm and therefore maintain the higher storm loss for a longer period of time. Such cables have been shown to retain and gradually exude the necessary lubricating grease to a greater extent and thereby collect dirt upon their surfaces which will, no doubt, increase the corona losses with age. Relatively high storm losses have been found in the Purdue University tests as well as those reported in this paper.

Unfortunately, either the rather complicated methods of measurement, apparently not confirmed or calibrated elsewhere, were not precise enough to detect the variation in corona losses resulting from the various sizes of strands or else the other variables, as previously explained, caused such large variations in losses in the different tests as to neutralize the effect of varying strand sizes. It should be noted in this connection that in 2 tests the losses were practically the same with different sizes of strands: (See Types *D* and *E* of Fig. 12 and curves 2 and 3 of Fig. 13) while in another test the same size of strands provided different losses, since those of cable *E* (curve 4) are lower than those of cable *B* (curve 2) in Fig. 12.

With regard to the ratio of computation of 3-phase losses based upon single-phase tests which was used in some cases, it should be pointed out that with cables spaced as widely as 30 ft and supported only 30 ft above the ground, the neutral plane of the ground itself affects the losses between each individual cable and ground. The neutral point of the 3-phase circuit is shifted downward, therefore, by the nearby ground plane to such an extent as to introduce an error into the 3-phase vs. single-phase ratios which would be otherwise correct. It would be preferable to base such transfer calculations upon comparative 3-phase vs. single-phase empirical test data with the actual spacings to be used. Tests at Purdue University have indicated that with spacings of 30 ft and more, the corona losses due to the proximity of the ground plane were practically constant for a given potential and height of cable regardless of horizontal spacings.

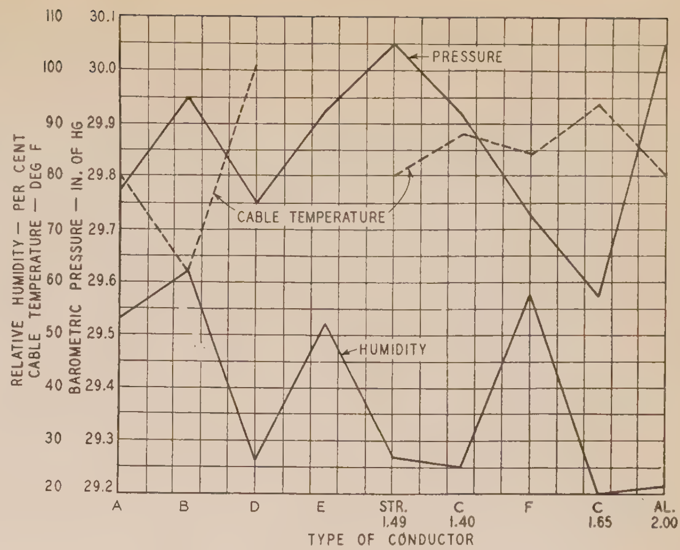
Although much has been said about the variation of corona losses upon different types of cables, particularly under the unusually immune test conditions outlined in this paper which will not, of course, exist upon the actual line, it should be emphasized that corona loss is not an evil necessarily to be avoided. Such losses will, no doubt, exist upon portions of this line, at least at the high altitudes and/or under storm conditions and may prove to be a very valuable safety factor in the attenuation of surges. It has been shown by means of surge generator tests and cathode ray oscillograms at Purdue University and elsewhere that steep-wave-front surges, superimposed upon an energized 60-cycle power line, are attenuated much more rapidly than otherwise if the line is operating near the critical potential and the surge is of opposite polarity from the 60-cycle wave. It is probable, therefore, that the possibilities of corona formation upon this rather exposed line will provide an important protection against damage to insulation as well as to generating and receiving equipment during lightning storms.

Notwithstanding the general usage of the Peek corona formula, which was a most commendable contribution to the design of the early lower potential transmission lines, the subsequent test data which are being

gradually accumulated lead us annually farther away from his constants for extra high-potential large conductor specifications. Practically all of the tests carried on by the writer throughout the past 20 years have shown larger losses in the lower range of potentials than those calculated from the Peek formula, while the test losses are lower than those of the formula throughout the higher potential ranges. It should be noted that the formula proposed by W. S. Peterson (see "Development of a Corona Loss Formula," discussion, A.I.E.E. TRANS., v. 52, 1933, p. 62) recognizes increased losses due to higher humidity, but unfortunately interrelates humidity and surface irregularity factors which probably do not have any correlation whatsoever.

It is hoped that before there is a demand for another line above 220 kv, there will be available some more exhaustive tests of long duration involving daily readings over wide ranges of humidity as well as temperature, barometric pressure, cable sizes, and surface contour.

Fig. 1. Range of temperature, barometric pressure, and humidity for the corona loss tests reported in the Carrol, Cozzens, and Blakeslee paper



J. H. Foote: It is gratifying that the facilities at the Ryan Laboratory allow such full scale tests as the authors describe. The fact that the tests have been conducted with spacings, insulation, conductors, and span lengths similar to those to be used on the line, greatly enhances their interest and practical value.

The paper shows that since all the conductors tested appear to have a critical voltage in excess of the operating voltage, the conductor diameter chosen (1.4 in.) is probably very ample indeed. In fact, the losses at the operating voltage with fair weather are so small that the differences registered by various surface conditions and conductor types are of almost negligible value.

The small actual corona loss to be expected is emphasized by comparison with the insulator loss. In a previous paper "Corona Loss Measurements on a 220-Kv 60-Cycle 3-Phase Experimental Line" the losses in a 13-unit insulator string ranged from $3^1/_2$ watts per string at 45-per cent humidity to 172 watts at 81-per cent humidity with 295 kv potential between lines. While these losses may appear negligible with fair weather, they assume appreciable magnitude during foul weather or high humidity. At 172 watts per string with 7 spans per mile they amount to 3.6 kw per circuit mile, and even at 5 watts per string in fair weather they will be $^1/_{10}$ kw per mile which approaches the losses of the most efficient conductor tested.

It would seem that, while the results are of interest in showing the losses of various constructions at potentials considerably above operating voltages, they also show that the operating corona losses ol any of the conductors tested are relatively unimportant from an economic standpoint, and therefore with the diameter of the conductor fixed at 1.4 in., the corona loss characteristics do not here constitute an important factor in the selection of the conductor construction.

It is probable that similar tests conducted under abnormal atmospheric conditions would be of interest. Of course, it is difficult to make to order any desired weather conditions. The authors were fortunate in being able to make one test during a rain storm on the type *A* conductor. This test showed that the losses during the rain, at the particular voltage existing during the test, were 16 to 20 times as great as similar tested losses under fair weather conditions. It would seem that perhaps more consideration should be given to the comparative performance of the various types of conductors in stormy weather. It woufd be expected that the smoother segmented conductor designs would have lower losses during fair weather than would the stranded construction. Whether this would be true under less favorable weather conditions might be subject to argument.

In interpreting test results and using them in making a choice of materials or constructions, it is essential that the scope of the tests from which the results are obtained coincided with the expected operating conditions. Since the tested corona losses within the operating range are so small in magnitude and the variation in tested losses of the different constructions of even less significance within this operating range, it is assumed that the choice of conductor type was based upon other considerations. Tests on the mechanical properties of the various types of conductors probably were made and details of these would be of considerable interest.

Attenuation and Distortion of Waves

Discussion of a paper by L. V. Bewley published in the December 1933 issue, p. 876–84, and presented for oral discussion at the power transmission session of the winter convention, New York, N. Y., Jan. 24, 1934.

A. R. Miller: Each new paper on traveling waves seems to add to the generality of our fundamental principles and methods. For some time certain discrepancies have occurred between the observed and calculated results, and have been variously explained—one might say guessed at; but Bewley coordinates to a greater extent some well known physical conditions of the problem and obtains solutions that bring calculated and observed values into much closer agreement. Thus, recognizing that corona changes the effective diameter of the conductor in so far as the electrostatic field is concerned and that the current distribution in the ground is quite different than is ordinarily assumed, very interesting phenomena are brought into light.

If 2 similar wires, spaced such that the distance between them is large compared to their radii, and are further assumed to be so located as to establish a system in themselves, the general solution requires 2 waves each of voltage and current traveling in opposite directions over the wires. Moreover, the ratio of the voltage to current wave traveling in one direction to those traveling in the other direction is the same in magnitude, but opposite in sign. The sign in this case simply indicates that the same electrostatic field traveling in one direction sets up a magnetic field in the opposite direction to that produced by the same field traveling in the opposite direction, which is in agreement with our fundamental notions of electromagnetic fields. This is the ideal case, in which the electrostatic and magnetic fields are orthogonal.

In the more practical case in which corona and ground conductivity are taken into consideration, and when one circuit is mutually related to another as in the case in Appendix I, there is found to be 4 waves required in the general solution, for both the current and the voltage. Thus, in one direction travels voltage (and current) waves of velocity v_1 and v_2. In the opposite direction are similar voltage and current waves of the same velocity. The more general solution is as follows:

Let the general voltage-current relationships be written as

$$\frac{\partial e_1}{\partial x} = Z_{11}\, i_1 + Z_{12}\, i_2 \tag{1}$$

$$\frac{\partial e_2}{\partial x} = Z_{21}\, i_1 + Z_{22}\, i_2 \tag{2}$$

$$\frac{\partial i_1}{\partial x} = Y_{11}\, e_1 + Y_{12}\, e_2 \tag{3}$$

$$\frac{\partial i_2}{\partial x} = Y_{21}\, e_1 + Y_{22}\, e_2 \tag{4}$$

where Z and Y are functions of p, in terms of the circuit constants.

Solving these equations simultaneously for e_1 (say) gives

$$e_1 \left\{ \frac{\partial^4}{\partial x^4} + (Z_{11}Y_{11} + Z_{12}Y_{11}) (Z_{12}Y_{12} + Z_{22}Y_{22}) \frac{\partial^2}{\partial x^2} + \left[(Z_{11}Y_{11} + Z_{12}Y_{11})(Z_{12}Y_{12} + Z_{22}Y_{22}) - (Z_{11}Y_{12} + Z_{12}Y_{12})(Z_{11}Y_{11} + Z_{22}Y_{11})\right]\right\} = 0 \quad (5)$$

Exactly the same solution can be obtained for e_2, i_1, and i_2. Thus there is a quartic equation in the general case yielding 4 roots $-K_1$, $-K_2$, $+K_1$, and $+K_2$ and the solution for e_1 is

$$e_1 = A_1\epsilon^{K_1x} + B_1\epsilon^{-K_1x} + C_1\epsilon^{K_2x} + D_1\epsilon^{-K_2x} \quad (6)$$

and for e_2

$$e_2 = A_2\epsilon^{K_1x} + B_2\epsilon^{-K_1x} + C_2\epsilon^{K_2x} + D_2\epsilon^{K_2x} \quad (7)$$

where the coefficients are functions of t but not of x.

By use of eqs 1, 2, 3, and 4 the following relationship can be obtained for corresponding coefficients in eqs 6 and 7.

$$e_2 = \frac{(Z_{11}Y_{11} + Z_{22}Y_{12})}{\frac{\partial x^2}{\partial^2} - (Z_{12}Y_{12} + Z_{22}Y_{22})} e_1 \quad (8)$$

Putting terms with like exponentials into eqs 1 and 2

$$A_1K_1\epsilon^{K_1x} = Z_{11}i_1 + Z_{12}i_2 \quad (9)$$

$$A_2K_1\epsilon^{K_1x} = Z_{21}i_1 + Z_{22}i_2 \quad (10)$$

Solved simultaneously,

$$i_1 = \frac{(A_1K_1\,Z_{22} - A_2K_1Z_{12})}{(Z_{11}Z_{22} - Z_{12}Z_{21})}\epsilon^{K_1x} \quad (11)$$

$$i_2 = \frac{(A_2K_1Z_{11} - A_1K_1Z_{21})}{(Z_{11}Z_{22} - Z_{12}Z_{21})}\epsilon^{K_1x} \quad (12)$$

These are the currents associated with the first voltage in eqs 6 and 7, respectively. It should be remembered that A_1 and A_2 are not independent in these expressions. Also, similar relationships hold for the B voltages in eqs 1 and 2 except for reversal of sign; the C and D voltages are related similarly.

In view of the foregoing, eqs 6, 7, and 8 may be written as

$$e_1 = f_1(x - v_1t) + f_2(x - v_2t) + f_3(x + v_1t) + f_4(x + v_2t) \quad (13)$$

$$e_2 = a_1f_1(x - v_1t) + a_2f_2(x - v_2t) + a_1f_3(x + vt) + a_2f_4(x + v_2t) \quad (14)$$

for each voltage impressed upon the system. Current waves are obtained by eqs 11 and 12.

The equations developed in the paper assume only inductive and capacitive circuit constants. That is, resistance and "leakance" are neglected. The addition of the latter would not affect the number or velocity of the waves, but would complicate to a very great degree the interrelationships between them. In a particular case the voltages given in eqs 13 and 14 are related to each other through the terminal impedances by their reflection characteristics.

Joseph Slepian: Mr. Bewley has proposed a very bold and interesting method for explaining the observed manner of propagation of waves along systems of conductors parallel to a plane earth of finite resistivity in terms of component waves, which seems to have considerable success in a qualitative way. This success makes it seem likely that there is a correct or true element in Mr. Bewley's proposed method. On the other hand, I believe that there are incorrect elements in Mr. Bewley's method which lead to false conclusions.

For simplicity in discussion, I shall consider only a 2-conductor system, with zero resistance of the conductors, zero leakage between conductors (i. e., no corona) but with a resistive earth. It is necessary to ascribe finite resistance to the earth, for otherwise the zero-potential plane for the magnetic field necessarily would be in the surface of the earth; i. e., the actual earth currents would be confined to the earth's surface, contrary to the assumption of Mr. Bewley that it lies below the earth's surface. The departure of the effective velocity of propagation of the waves from that of light can come only from this earth resistivity, if we assume that the dielectric constant of the whole space including the earth is unity.

I think that the correct element in Mr. Bewley's method may be the following, perhaps true, theorem: Any wave system on the 2 conductors can be regarded as the superposition of 2 wave systems, with the following characteristics: For each wave system, the shape of the wave of potential is the same on each conductor, and therefore the shape of the wave of current is also the same on each conductor. The ratio of the amplitudes of potential waves on the 2 conductors is, however, different for the 2 wave systems. The ratio of the amplitude of the potential wave and current wave on one conductor is also different for the 2 wave systems. Each wave system, however, does not propagate according to ideal wave theory, with unchanging amplitude and shape as Mr. Bewley assumes, but each wave system undergoes attenuation and distortion, because of the resistance of the earth, at rates that are different for the 2 systems.

This theorem is certainly true when the 2 conductors are at the same height above the earth as is evident from symmetry considerations. Then, the 2 wave systems consist respectively of (1) potentials of equal magnitudes and like sign on the 2 conductors, and (2) of potentials of equal magnitude but opposite sign on the 2 conductors. Because of the smallness of the earth currents for the second system, the attenuation and rate of distortion for it will be small compared to the corresponding quantities for the first system.

If this theorem be true in general (and if it is new) then Mr. Bewley has made another very valuable contribution to the theory of propagation of waves on systems of parallel conductors. The resolution of an actual wave system into a sum of these special component wave systems should prove a tremendously valuable aid in the analysis of waves on conductor systems, even though I believe Mr. Bewley is wrong in concluding that these component systems each propagate with only small attenuation and distortion, and at definite velocities which are independent of the wave shape of the component waves.

I believe that Mr. Bewley makes a very fundamental error in writing eq 1 for waves which propagate at velocities other than the velocity of light. This error is made quite generally in textbooks dealing with waves on wires, where it is usually deduced from the differential equations:

$$L\frac{\partial i}{\partial t} = -\frac{\partial e}{\partial x} \qquad C\frac{\partial e}{\partial t} = -\frac{\partial i}{\partial x}$$

that waves travel with $\dfrac{1}{\sqrt{LC}}$, the velocity of light, instead of recognizing that the equations themselves cannot be written unless we first assume that we are dealing with waves that travel with the velocity of light. To make this clear, consider the second of these 2 equations. It is derived from the obvious relation that the time rate of change of the charge Δq on a given short element of line of length Δx is equal to the difference of the current flow into and out of the 2 respective ends of Δx.

$$\frac{\partial}{\partial t}(\Delta q) = -\frac{\partial i}{\partial x}\Delta x$$

Now, if C is the capacity per unit length of line, it is usually stated that $C\Delta x$ is the capacity of the short length Δx, so that $\Delta q = C\Delta xe$ giving the equation

$$C\frac{\partial e}{\partial t} = -\frac{\partial i}{\partial x}$$

But right there, the great mistake is made: The capacity of the short length of line Δx is not $C\Delta x$, unless the charge on Δx may be regarded as moving with the velocity of light. If the charge on Δx is at rest, for example, then the lines of electric force do not all lie in planes perpendicular to Δx, so that a proportionality between Δq and Δx is obtained; but some will reach out forward ahead of Δx, and some will reach out behind, so that the charge will be considerably larger than $C\Delta xe$ where e is the integral to infinity of the electric force taken in a plane perpendicular to Δx. This discrepancy will get relatively larger and larger, the smaller Δx is made. Clearly then the foregoing differential equation, which requires that Δx shall be made to approach zero, cannot be derived if the charge Δq is at rest. Incidentally, this shows that the wave equation cannot be correct at the end of a line, even for waves traveling with the velocity of light, because lines of force will reach out beyond the end, and will cause a loss of energy at a reflection there not predicted by the wave equation.

According to the usual Maxwell theory, the lines of electric force from a point charge at rest, reach out radially straight in all directions. However, if the charge moves, the lines of force are no longer straight, but while starting out radially in all directions, turn laterally into directions perpendicular to the direction of motion. As the velocity of the point charge increases, the lines of force turn out more sharply, until finally at the velocity of light they all lie entirely in the plane through the point charge perpendicular to the velocity. This is caused by the electric field induced by the magnetic field arising from the motion of the charge.

Now we may see that if the charge Δq on the element of line Δx is moving with the velocity of light, then the lines of electric force will all lie in planes perpendicular to Δx, Δq will equal $C\Delta xe$, and the differential equation of wave motion may be derived.

Similar discussion can be given for the first of the 2 wave equations. The inductance of an element of line cannot be taken as $L\Delta x$ where L is a constant, unless the current i there can be regarded as part of a wave traveling with the velocity of light. Only then will the magnetic field of the current element $i\Delta x$ be confined to the perpendicular slab of space including the element Δx. This is because the Maxwell displacement currents also contribute to the magnetic field.

These remarks all apply to Mr. Bewley's eqs 1. The equations can be derived only if we assume that they describe waves traveling with the velocity of light. Otherwise, they cannot be deduced.

As mentioned before, the confining of the lines of electric force of the moving element of charge to the perpendicular slab of space including the charge element is due to the electric field induced by the magnetic field, and the confining of the magnetic field of the current element to the perpendicular slab of space is due to the magnetic effects of the Maxwell displacement currents accompanying the electric field. The electric and magnetic fields are thus closely interrelated. Therefore, we may not make arbitrary independent assumptions as to the nature of the electric and magnetic fields. Mr. Bewley, therefore, must not assume arbitrarily that the electric field may have one plane of zero potential, and the magnetic field another plane of zero (vector) potential. If the electric and magnetic fields have everywhere the perpendicular slab distribution that is assumed in setting up eqs 1, then the zero-potential plane must be the same for both fields.

The 2-conductor system with resistive earth to which I have chosen to limit my discussion, may be expected to show the essential phenomena which Mr. Bewley has described and which he aims to explain. From the discussion which I already have given, it is clear that these phenomena must owe their origin to the lack of perfect conductivity of the earth. In fact, to produce currents in the earth parallel to the conductors, a parallel electric force is necessary. Hence the lines of electric force in space must have a component parallel to the conductors, and they will not lie everywhere in planes perpendicular to the conductors. Such waves as may be discerned therefore will travel with less than the velocity of light, but they will not be governed by Mr. Bewley's eq 1.

The existence of this parallel component of the electric field brings about the remarkable and at first sight paradoxical effect that a neighboring insulated wire has upon the propagation of waves in a given wire. The insulated wire can have an effect on the wave-bearing wire only if currents flow along it, for only with such currents can charges appear upon it; but if the electric field set up by the wave-bearing wire was perpendicular to the insulated wire wherever it encountered it, it is clear that no currents would be started in the insulated wire.

The existence of the parallel component of electric field makes clear in another way why Mr. Bewley's eqs 1 must be invalid. If the lines of electric force are not everywhere perpendicular to the conductors, then the potential at a point on one conductor is determined by the charge on the other conductor not at the same point, that is at the same value of x, but at some other point which will be ahead or behind depending on the inclination of the lines of electric force. Hence, eqs 1, which assume that the charge at any point of one wire is determined entirely by the potential there and the potential at the same point of the other wire, must be invalid.

It might be argued that with wave fronts of several thousand feet in length, and wire and ground separations of less than 50 ft, the parallel component of the electric field will be small compared to the perpendicular component and that therefore the wave equations have an approximate validity. However, we have just seen that the phenomena of attenuation and distortion which it is our business to explain owe their origin to the parallel component of field; therefore, it is difficult to see how we may hope to explain these phenomena by neglecting the very factor that brings them into being.

The criticism just given applies only to the eqs 1 which claim to govern the propagation of Bewley's component wave systems. The justifiability of the resolution into component systems of the type described, each traveling with its own velocity and manner of attenuation and distortion, seem to be plausible and apparently supported by experiment. The effective velocity of each component wave system, however, should be expected to depend on the wave shape, and should change during the propagation as distortion varies the wave shape, after the manner of waves on a single wire having finite resistivity.

R. D. Evans: Both of the papers dealing with surge propagation phenomena that have been presented today employ assumptions as to the equivalent depth of the earth return circuit. The calculation of the fundamental phenomena in a circuit with ground return assuming uniform resistivity of finite value is an extremely difficult problem. Much work has been done toward the determination of the steady state constants of these circuits by methods introduced by J. R. Carson. It seems to be of interest to consider what equivalent depth of earth return would be indicated by these methods for the resistivities of earth encountered in practice and for a frequency that might be considered comparable to lightning waves. The extensive work by the Joint Development and Research Subcommittee of the N.E.L.A. and Bell Telephone System has indicated that the resistivity of the earth varies between 1 and 10,000 meter ohms. Using an arbitrary high frequency, such as 1,000,000 cycles, the equivalent depths of return for conductors located 100 ft above the surface of the earth are indicated by these methods for (1) magnetic effects to vary between 215 and 460 ft and (2) for electric effects negligibly greater than 200 ft

Doctor Fortescue in his paper is concerned with application of the counterpoise to high resistance areas and assumes an equivalent depth of 400 ft. These calculations tend to support Doctor Fortescue's assumptions considering electromagnetic effects. While this method of getting at the depth of earth return may be criticized, as it is based on steady state rather than transient constants, yet it does seem pertinent to point out that the method gives values which check those indicated by the surge studies of Fortescue and Bewley.

It would appear for the front of the wave that the constants should be calculated on the basis of the same equivalent depth for both magnetic and electric effects, whereas for the tail of the wave greater depth should be assumed for magnetic effects than for electric effects. It seems unnecessary to assume, as Mr. Bewley has done, that the same equivalent depth should be used in computing constants applicable for both front and tail of the wave.

Power Limits of 220-Kv Transmission Lines

Discussion of a paper by Alex A. Kroneberg and Mabel Macferran published in the November 1933 issue, p. 758–66, and presented for oral discussion at the power transmission session of the winter convention, New York, N. Y., Jan. 24, 1934.

S. B. Crary: The authors have done a creditable piece of work in showing how the stability limits can be increased over that of the "simplest possible layout" with the expenditure of a relatively small additional investment. They have based their conclusions as to the benefits to be realized from each factor for improving stability on the gain in the transient stability limits as determined by the first swing of the machine rotors. Care must be taken in using the results of a transient stability analysis made in this manner as the stability limits of the subsequent swings or the steady state stability limits with the faulty line switched out may be below the limit as determined by the first swing. When the switching and relaying is fast, the maximum power that can be transferred through a disturbance may be determined by the steady state limits rather than the transient limit of the first swing. For example, the gain that the authors have credited to the series braking resistor over the base design cannot all be realized as the steady state stability limit with the faulty section switched out is probably in the neighborhood of 250,000 kw. This is below 300,000 kw, the transient limit obtained by the authors when the series braking resistor is used.

A further decrease in the practical gain to be realized by the use of series braking resistors is brought about by the fact that most systems are designed to have some margin between the steady state stability limit and the rated output of the station. For example, if the steady state stability limit is 250,000 kw and the rated output is 225,000 kw, which assumes only a margin of 10 per cent between the rated output and the steady state stability limit, it would seem unnecessary to provide equipment to raise the limit during the first swing to 300,000 kw when all the line normally will be expected to carry is 225,000 kw and all it can carry is 250,000 kw.

Consideration should be given also to the switching off of the braking resistors. Although the braking resistor will increase the power output of the generator, it will do so at a sacrifice of the synchronizing power between the generators and the receiving end system. This will increase the transient stability limits during the first swing, but will decrease the power limits of the subsequent swings as the machine groups oscillate about each other. The ideal arrangement, in order not to reduce the steady state limit or the limits of subsequent swings, would be to insert the resistors in the circuit only during the period when the fault is on or only during the first swing of the machine rotors.

However, even assuming that the braking resistors are used in this ideal manner so that it does not reduce the limit of subsequent swings, the steady state limitations

of a 280-mile 220-kv line are such that only a small practical gain can be realized by the use of series braking resistors when switching times of 0.2 sec or less are used. These features of the use of braking resistors will be found more fully discussed in the discussions of R. C. Bergvall's paper "Series Resistance Method of Increasing Transient Stability Limit," which was published in volume 50 of the A.I.E.E. TRANSACTIONS.

The authors' calculations of the power limits are simplified by assuming that the complements of the driving point and transfer impedance angles are small, and that $(P_1 - P_{11})$ is approximately equal to $(P_{22} - P_2)$. These assumptions, I believe, will lead to appreciable error in some cases and therefore cannot be applied generally to problems of this type.

The authors state by eq 13 that the change in kinetic energy of the rotor is proportional to the integral of the accelerating torque times the differential of the relative angular displacement, $d\delta$. This would be true if δ were the actual angular displacement with respect to some fixed axis in space rather than the relative angular displacement between the 2 rotors. The criterion developed by R. H Park for 2 machines and referred to by the authors is that the relative angular velocity of the rotors, $\frac{d\delta_{12}}{dt}$, is zero, not that the change in their kinetic energy is zero, when the following relation is satisfied

$$\int_{\delta_0}^{\delta} \left(\frac{T_{a1}}{H_1} - \frac{T_{a2}}{H_2}\right) d\delta_{12} = 0$$

This criterion generally is called the equal area criterion. Frequently it is explained loosely by means of the concept of change in kinetic energy while it should be understood to be the criterion which determines when the relative angular velocity between the rotors is zero, and not necessarily when the change in their kinetic energy is zero.

R. D. Evans: It is very gratifying to review the paper by Kroneberg and Macferran because it suggests the progress in stability that has been made in the last 10 years, during which time there have been presented many papers dealing with stability theory, laboratory tests, measures to improve stability, field tests, and operating experience; this paper is noteworthy because it gives economic comparisons of various system layouts which are analyzed from the stability point of view. The paper might be extended, however, to include evaluation of relative speeds of fault clearing. Since April 1932, when the paper was submitted to the A.I.E.E., there has been considerable progress in the development of circuit breakers and relays. The fault clearing time of 0.2 sec used in the paper is now viewed as conservative. This increased speed of fault clearing provides an additional factor that should be evaluated in relation to the other factors for stability improvement.

G. D. Floyd: The authors are to be commended for giving a very clear analysis of the factors influencing the power limit of 220-kv lines. In the past, the majority of the papers presented before this Institute have been concerned practically entirely with the technical features of the problem, without any data covering the costs of the various items. The reason for this was because the authors were probably not in a position to discuss this important feature.

Referring to Fig. 2 of the paper, I believe these curves illustrate a point that is of first significance, but which often is not fully appreciated. This is, that other things being equal, the power limit is a function of the synchronous capacity connected to the system, including transformer capacity. No intelligent or correct answer can be given to the question "What load can be carried on a given line?" unless the terminal conditions are specified.

I do not propose to criticize the data presented in this paper, which are no doubt correct for the conditions laid down. However, these data and the conclusions drawn from them may give a wrong impression. One would be led to believe that unless the special features analyzed in the paper are incorporated in the system, poor operating characteristics will result. This is not the case. If the transmission line is well designed, there will be, on the average, possibly 1 or 2 outages per year of a type equal to or greater than the authors set as a limit. The effect of these on the system as a whole may be tempered by a number of factors, 2 of which are:

1. The location of the fault, which may not be such as to produce the most severe oscillation.

2. The time of outage, which is quite likely to be at a time other than when the system is heavily loaded.

If these and other factors are considered, it does not seem that justification can be found for very much additional expenditure on equipment.

In the final analysis, it becomes a matter of judgment as to how far one would be justified in incurring additional expense in order to prevent an outage very likely to be of short duration, and with very little, if any, serious effect on system operation. The authors have not discussed this factor of probability, and it seems to me that the question of whether or not the system shall have special features incorporated in it cannot be decided unless this factor is considered. I believe members of the Institute would be interested to know which, if any, of the features of design considered by the authors actually have been incorporated in the system.

Nothing I have said will detract from the value of this paper. The authors set out a criterion for the stability limit of the system and analyzed it, showing the improvement to be expected from a stability standpoint, if various features were incorporated, giving also the increase in cost to obtain these features. I believe, however, that there is a place in this discussion for the points I have raised, and I hope they will be discussed further.

I would like to raise one other question: The authors have made no reference to the possibility of building a lightning-proof line. It has been stated more than once that such a line can be built. It may be possible to do it at equal or less cost than what would be incurred for the special features discussed in this paper. If such a line can be built economically, the stability limit then becomes the steady state limit, which as the authors have stated, is many times the lower or transient limit. All system faults, of course, are not caused by lightning; but if these latter are eliminated, the probability factor would make additional expenditure on account of instability unjustified, and therefore unnecessary.

W. W. Lewis: On page 761 of November 1933 issue of ELECTRICAL ENGINEERING, Kroneberg and Macferran discussed Petersen coils briefly and drew the following conclusion:

"Hence, it is safe to conclude that the possibility of using Petersen coils, at least in connection with 220-kv transmission, definitely should be rejected."

Probably what the authors intended to convey was the thought that in connection with their particular study, which pertained almost entirely to stability, Petersen coils did not show any advantage because their installation required 1 to 1 ratio isolating transformers and the reactance of these isolating transformers had the effect of reducing the stability limit. In addition, the cost of the Petersen coils and the isolating transformers had to be taken into account in evaluating the benefits of the Petersen coils. Where stability is not a factor, or under other circumstances, different conclusions may be justified and Petersen coils may be found to be applicable.

S. M. Zubair: One of the most significant features of the paper is the fact that transient stability power limits could be calculated directly by the integraph curves. The authors were able to avoid the step-by-step method of calculation by introducing the 2 approximations discussed in Appendix IV. The second approximation, however, is not necessary because if the last term of eq 9 is neglected (first approximation only) eq 8 gives:

$$\frac{E_1E_2}{Z_{12}} \cos \alpha_{12} \sin \delta - \frac{M_2(P_1 - P_{11}) + M_1(P_{22} - P_2)}{M_1 + M_2} = - \frac{M_1 M_2}{(M_1 + M_2)2\pi f} \frac{d^2\delta}{dt^2}$$

which readily becomes eq 24

$$\frac{d^2\delta}{d\tau^2} + \sin \delta = \frac{E}{B}$$

if

$$B = \frac{E_1E_2}{Z_{12}} \cos \alpha_{12}$$

$$E = \frac{M_2(P_1 - P_{11}) + M_1(P_{22} - P_2)}{M_1 + M_2}$$

and

$$\tau = t \sqrt{\frac{2\pi f\,(M_1 + M_2)\,B}{M_1 \times M_2}}$$

It is interesting to note, however, that the integraph solution can only be used if eq 24 does not contain a cos δ term. This necessitates the first approximation:

$$\frac{M_1 - M_2}{M_1 + M_2} \frac{E_1E_2}{Z_{12}} \cos \delta \sin \alpha_{12} = 0$$

or

$$\frac{M_1 - M_2}{M_1 + M_2} \sin \alpha_{12} = 0$$

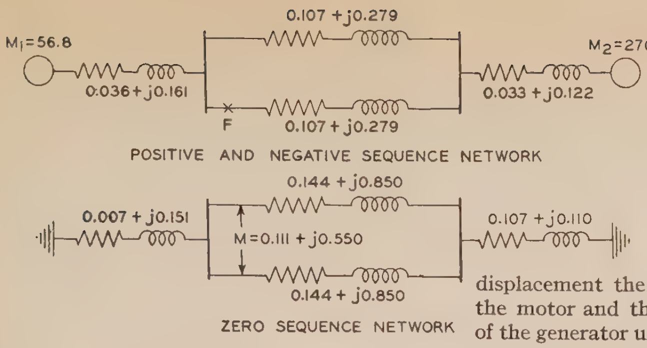


Fig. 2. Representation of a 110-kv system in which α_{12} is too high to be neglected

Theoretically this condition is obtainable only when either $\alpha_{12} = 0$ or $M_1 = M_2$. Since $\alpha_{12} = 90 - \tan^{-1}\dfrac{X_{12}}{R_{12}}$ where $R_{12} + jX_{12} = Z_{12}$, the transfer impedance, the value of α_{12} will decrease as the ratio of $\dfrac{X_{12}}{R_{12}}$ increases. In a 220-kv system where the ratio of reactance to resistance is high, the value of α_{12} may be negligible, but in a 110-kv system α_{12} may be too high to be neglected. This is illustrated in Fig. 2. For a 2-phase-to-ground fault at F, the equation of the relative angle of the 2 rotors is $0.83 \sin\delta - 0.19 \cos\delta - 0.317$

$$= -\frac{46.8}{2\pi f}\,\frac{d^2\delta}{dt^2}$$

where the cos δ term could not be neglected and therefore the integraph curves cannot be applied.

Steady State Stability of Composite Systems

Discussion of a paper by S. B. Crary published in the November 1933 issue, p. 787–92, and presented for oral discussion at the power transmission session of the winter convention, New York, N. Y., Jan. 24, 1934.

H. L. Hazen: See p. 477.

Power Limits of Synchronous Machines

Discussion of a paper by Edith Clarke and R. G. Lorraine published in the December 1933 issue, p. 780–7, and presented for oral discussion at the power transmission session of the winter convention, New York, N. Y., Jan. 24, 1934.

S. B. Crary: The authors have presented in concise form for practical calculations criteria for determining the steady state power limits of 2, 3, 4, and 5 synchronous machines. The relative simplicity of these criteria was made possible by using a method of testing for stability which is different from that previously used and which, I believe, is worthy of more discussion than that given in their paper. They have chosen the criterion that stability exists if for a sustained increase in angular displacement the electrical power input to the motor and the electrical power output of the generator units of the system increase, constant system frequency being maintained. This criterion is different from that used by Wagner and Evans and presented in their paper "Steady State Stability" (A.I.E.E. TRANS., v. 47, 1928, p. 94). Wagner and Evans used the criterion that the system is stable if it returns to its original assumed operating position after one of the rotors has been forcibly displaced from its original operating point. These 2 methods of analysis indicate different stability limits in certain regions of operation. The difference in the 2 methods can be demonstrated clearly by considering 2 machines operating at or near 90-deg relative angular displacement, the region where this difference exists.

Consider 2 synchronous machines, a generator and a motor, connected together by means of a line having resistance and reactance and operating with 90-deg angular displacement. Their torque angle characteristics will be as shown on Fig. 2 of the paper. The equal area criterion derived by R. H. Park (reference 4 of the paper), provides a method for analyzing the phenomena at this point. A diagram of the ratios of their accelerating torques to their respective inertias with constant mechanical torques plotted against relative angular displacement will appear as shown in Fig. 3(a) for a large generator inertia compared to the motor inertia, and as shown in Fig. 3(b) for a small generator inertia compared with the motor inertia. Referring to Fig. 3(a), it can be seen that if the angular displacement δ_{12} is increased suddenly, the motor will slow down more rapidly than the generator (the length ac is greater than ab and synchronism will be lost as there will be no restoring forces to bring the machines back to their normal operating position. If an increase in load is thrown on a motor operating at such a point, the accelerating torque per unit of inertia curve for the motor changes to that shown by the dotted line. This results, therefore, in a retarding torque acting on the rotor of the motor equal at the first instant to the increase in load (the distance $od \times H_2$) which causes the motor to slow down more rapidly than the generator, and the system is unstable. Therefore, for this case, both methods of testing for stability would find the system unstable for this particular condition.

Next consider the case when the motor inertia is large compared with the generator inertia as shown in Fig. 3(b). A momentary forcible increase in the angular displacement δ_{12} will result in the generator's slowing down more rapidly than the motor (the distance ac is greater than ab) thus returning the system to its original operating position. This method of testing for stability therefore indicates a stable operating point. Now consider a small increase in motor load with constant system speed. This will result in the slowing down of the motor at the first instant as is shown by the distance od. As the angular displacement between the motor and generator increases, the generator slows down more rapidly than the motor and the system returns to a new position of equilibrium, o'. However, at o' the new point of equilibrium, there is a retarding torque acting on both the motor and generator due to the increased load and line losses represented by the distance $o'd'$ which results in a reduction in the system frequency. As the governor of the generator attempts to bring the system frequency back to normal, the curve of T_{a1}/H_1 in effect moves upward and the point of equilibrium o' moves down until synchronism is lost. Therefore, for the case of series resistance and with a large motor inertia compared with the generator inertia, the system in this region of questionable stability can operate with a momentary increase in angular displacement, but cannot for a sustained increase in motor load. The first fact is of theoretical interest while the latter is of practical importance.

In a similar manner the 2 cases when the generator and motor are connected to a shunt impedance can be analyzed by Fig. 4. Figure 3 of the paper shows the shape of the

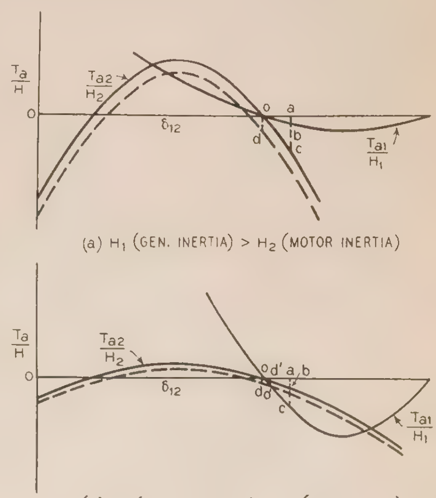


Fig. 3. Generator and motor connected by a series resistance

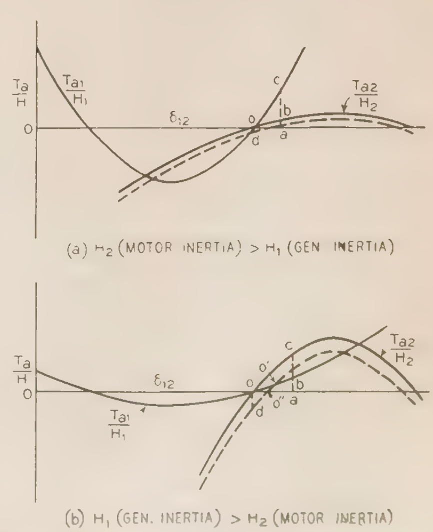


Fig. 4. Generator and motor connected by a shunt resistance

power angle characteristics for this case. Figure 4(a) of this discussion is for a small generator inertia compared to the motor inertia while Fig. 4(b) is for a large generator inertia compared to the motor inertia. The condition represented by Fig. 4(a) is unstable either for a momentary increase in angle or a sustained increase in load. The condition represented by Fig. 4(b), however, is stable for either type of load increase. In this case for a sustained increase in load on the motor, the generator and motor tend to reach a new point of equilibrium o' with constant governor input to the generator. Since this new point of equilibrium is above the line of zero accelerating torque, the system frequency increases. The governor on the prime mover of the generator decreases the mechanical input to the generator, which in effect moves the curve T_{a1}/H_1 down, until a new point of equilibrium o'' is reached with zero accelerating torques acting on both motor and generator. This case, Fig. 4(b), is the only case of the 4 which is stable for a sustained increase in load when one of the machines, in this case the generator, is operating with the slope of its power angle curve negative (negative synchronizing power coefficient).

The criterion for stability for this relatively simple case of 2 machines when machine 2 is subjected to a sustained small load increase is

$$-\frac{d\,P_2}{d\delta_{12}}\,\frac{1}{H_2} \quad \text{must be greater than} \quad -\frac{d\,P_1}{d\delta_{12}}\,\frac{1}{H_1}$$

When more than 2 machines are involved it becomes increasingly difficult to determine the exact stability limit for sustained increases in load in the region where one of the units has a negative synchronizing power coefficient. No simple relation such as the one given above can be used when more than 2 machines are involved. The answer depends not only on the relative inertias of the machines but on their rates of governor response as well. The authors, therefore, wisely have chosen the criterion for stability to be that each of the units have a positive synchronizing power coefficient. Such a criterion in some cases will result in pessimistic stability limits, but will not result in overly optimistic results as would be obtained if the method for testing was a momentary increase in angle or load. Consideration of the particular problem in hand after the synchronizing power coefficients have been calculated generally will indicate whether or not and to what degree the answer is pessimistic.

G. C. Dahl: The problem of steady state stability and power limits has been discussed in considerable detail for a dozen years or more. In spite of this fact it seems that no single criterion on the basis of which such stability should be determined has been definitely established and agreed upon. Surprising as this may be to some, it is nevertheless the case. Somewhat different schemes, all more or less justified by the nature of the problem, have been used by different investigators. It seems fortunate, therefore, that this question again is brought up for discussion with the possibility of settlement once and for all.

Besides depending upon (1) the electrical characteristics of machines and circuits, the ability of a system to operate stably in the steady state is influenced by (2) prime mover characteristics, and (3) inertia. In determining steady state stability and power limits, however, the 2 last-mentioned factors seldom are taken into account. To what extent this is justifiable and to what extent the various factors are important from the standpoint of influencing the problem of steady state stability never has been completely investigated. It would indeed be valuable to secure additional experimental results and to compare these with calculations based on different premises.

In the paper "Static Stability Limits and the Intermediate Condenser Station" by Evans and Wagner (A.I.E.E. TRANS., 1928) it is shown that under fixed shaft-load conditions (an assumption that eliminates any effect of prime mover characteristics) the steady state stability is influenced by inertia. In order to find the angle between the various machines at which the system may be operated stably, the inertia should be included in the calculations. With reference to a 2-machine system consisting of a generator, an impedance line, and a synchronous motor, this means that stable operation, theoretically at least, may take place when the machines are farther apart than the impedance angle of the connecting circuit (the latter including the impedance of the machines themselves). A power circle indicates the existence of 2 values of maximum power, one for the generator, and one for the motor. The latter is the smaller and hence usually the value of interest, i. e., it represents what ordinarily is termed the *power limit of the system.* If the generator inertia is infinite, the angular displacement at this value of power represents the limiting stability angle. If, on the other hand, the motor inertia is infinite, the angular displacement may be increased to that corresponding to maximum power of the generator. For finite values of inertia, operation is practicable over a part of the zone between these 2 limiting angles. It is evident that operation beyond the angle corresponding to maximum motor power can be established only by increasing the prime mover input to the generator. It cannot be established by any slow load application to the motor shaft, although it is conceivable that the system might settle in this region after a suitable transient application of load to the latter machine.

It is evident that since in a system, stability must be available when load is applied to any arbitrary machine, the region beyond the maximum power of the motor in the above case is of no great significance. Operation always will take place at an angle smaller than that corresponding to this power limit. In this region the question of stability can be settled without reference to inertia or prime mover characteristics, and the power limit can be determined without introducing the use of these factors.

It seems therefore that for a 2-machine system, stability and power-limit calculations can be performed in practice without consideration of prime mover characteristics and inertia. To what extent this is permissible with a multimachine system has not as yet been demonstrated. However, on the assumption that it may be done also here, I agree that the criterion by which each machine should be tested is that considered in the paper by Clark and Lorraine involving an infinitesimal load application to the shaft of the machine and the examining as to whether or not the requisite synchronizing power is available. I wish to raise a question, however, regarding the detailed aspects of the method by which such stability tests are executed.

The analysis is to be based on the following premises: constant frequency (i. e., no prime mover action) and no inertia effect. The assumption made in the paper in analyzing the multimachine system is that in giving one of the machines an infinitesimal displacement with respect to one of the others, the power outputs of the rest of the machines remain constant. This assumption is evidently contrary to fact except when the second machine involved is made to assume the entire load increment by automatic frequency control of the governor. This can only take place after the elapse of a certain time interval. It seems to me that since we are here considering an *incipient tendency* of one machine to become displaced due to the application of an infinitesimal additional shaft load, all other machines should be considered fixed in phase with respect to each other. This, in my opinion, gives a more logical basis in obtaining the power distribution between the other machines and the effect of this group with respect to the machine being tested, especially when the coupling between the single machine and the group is relatively loose. This, for instance, would be the case where a remotely located hydroelectric station supplies power to a metropolitan system over a long transmission circuit.

In conclusion I wish to say that I am glad that the question of criteria for steady state stability has been taken up again for discussion. It is of some importance to get complete agreement on these matters. As already stated, however, I believe that before this can be done, further experimental results and also analyses will have to be presented so that the effect of the various factors may be appreciated better. We have under way now at the Massachusetts Institute of Technology some work along these lines. We hope to secure a series of test results in our machine transients laboratory, and shall use these to check analyses based on different premises.

R. D. Evans: Clarke and Lorraine, under the heading of "Test for Stability," discuss operation at angles greater than α, the angle which corresponds to maximum power for the end which first encounters it. Maintenance of stability at greater operating angles was indicated by Wagner and Evans in their paper in 1927. Clarke and Lorraine do not disagree with this, but make a distinction between an arbitrary slight increase in angle and an arbitrary slight increase in load. They point out that for increase in load, equilibrium under initial conditions including frequency cannot be regained for operating angles greater than α. It is suggested that the 2 statements are not in conflict, but that each is correct for the conditions assumed. However, it may be observed that operation for angles greater than α may be not only of theoretical interest, but also of practical importance, if equilibrium can be secured at reduced frequency. In such cases normal frequency may be regained by redistribution of load without an interruption to

service, and such a system may be operated closer to the steady state power limit with the same margin of safety.

In Appendix III of this paper are given 3 separate cases for replacing a load end network by an equivalent network with an equivalent voltage and equivalent series impedance. The first 2 of these may be viewed as special cases of a more general method of using equivalent circuits applicable to systems in which synchronous machines maintain their internal voltages at constant value and definite relative phase position. This method may be illustrated by considering its application to 3 machines with voltages E_a, E_b, and E_c feeding through three impedances Z_{ax}, Z_{bx}, and Z_{cx} between the internal voltages and the junction point x. The equivalent impedances and equivalent voltages are defined by the eqs 1 and 3.

$$\frac{1}{Z_{eq}} = \frac{1}{Z_{ax}} + \frac{1}{Z_{bx}} + \frac{1}{Z_{cx}} \tag{1}$$

$$I_x = \frac{E_{eq}}{Z_{eq}} \tag{2}$$

$$= \frac{E_a}{Z_{ax}} + \frac{E_b}{Z_{bx}} + \frac{E_c}{Z_{cx}} \tag{3}$$

Additional machines can readily be handled by adding additional terms to eqs 1 and 3. A shunt load may be taken into account by setting the voltage of that branch equal to zero.

The series impedance branches may be replaced by a complex network with lumped or distributed constants. The proof for this generalized method was published in 1926 (A.I.E.E. Trans., v. 45, 1926, p. 75).

H. L. Hazen: In the study of the steady state stability of an n-machine system by power increment methods, the problem of distributing a load increment applied to one machine, for example, the k^{th}, among the remaining $(n - 1)$ machines arises. This distribution can be made on the basis of any one, or of a combination of the following assumptions: (1) that the relative rotor positions of the $(n - 1)$ machines remain unchanged, but that the group position changes with respect to that of the k^{th} rotor; (2) that the prime mover inherent speed regulation at constant gate or throttle is effective in determining the frequency-load characteristic of each unit and hence the division of load increment; (3) that the governors determine the frequency-load characteristics, the assumption made in Crary's paper ("Steady State Stability of Composite Systems," Elec. Engg., v. 52, Nov. 1933, p. 787–92); and (4) that the governor characteristics are readjusted in response to the load increment by automatic frequency controllers. In the paper by Clarke and Lorraine it is assumed that one machine is equipped with automatic frequency control.

The first of these assumptions, that the relative angular positions of the $(n - 1)$ machines are not changed, has been used by several investigators. This assumption would certainly be a fair approximation to the truth when the coupling of the k^{th} machine to any of the $(n - 1)$ machines is relatively loose compared to the couplings of the $(n - 1)$ machines with each other. In this case, although the division of an increment of load applied to the group may vary widely due to the fact that one of the other assumptions is more nearly valid than the constant relative angle assumption, the changes in relative angles within the group would be so small in comparison with the change in angle between any one of these and the k^{th} machine as to be quite negligible in their effect on the stability of the k^{th} machine. Since computations resulting from this assumption are readily made, it is very useful when applicable. That this assumption represents an accurate formulation of the physical relations significant in determining steady state stability in the more general case, in which the coupling between machines is more nearly equal, is, I believe, an hypothesis as yet lacking adequate experimental verification. In fact, since the relative angles among the $(n - 1)$ machines are constant only during a short time interval after any increment of load is added, it would appear that this assumption is probably not basicly applicable to steady state analysis. However, it may be very useful, practically.

The second assumption, that the load increment taken by any of the $(n - 1)$ machines is proportional to the machine rating and inversely proportional to the per-unit regulation at the given operating point of the prime mover at constant gate or throttle, represents a condition that will exist if the various rotors reach mechanical equilibrium before the governors have time to act. This assumption probably represents actual conditions rather well during a considerable period of time in the case of hydroelectric units in which the time for the prime mover torque correction through governor action may be relatively large compared to the period of the electromechanical rotor oscillations. In the case of turbine alternators, in which the response to governor action is substantially complete within a half second after a load change, this assumption probably does not represent the facts accurately at any time following an appreciable load change. However, in steady state stability analysis we are interested in very small load changes, in which the frequency change is very small. Even the most sensitive governor has a small but finite range, determined by friction and backlash, over which the speed may vary without causing the governor to respond. For variations of load that do not change the speed of the prime mover, by virtue of its inherent speed regulation, enough to cause governor action, this second assumption would appear to be reasonably in accord with the facts for a sufficient period during a slow system-load change to make it significant in steady state stability analysis. The mechanics of calculation on the basis of this assumption are identical with those given by Crary except that the governor per-unit regulation is replaced by the prime mover inherent regulation at constant throttle or gate.

The third assumption, that made by Crary, may very likely be the most appropriate for a practical case in which governors have a very small insensitive speed range and a relatively rapid response, and in which the load increments are applied at a finite though perhaps very small rate.

The fourth assumption, that automatic frequency controllers have the opportunity to act before conditions critical in steady state stability are reached, probably is useful as the authors state, not because it gives an accurate picture of the physical mechanism of steady state instability, but because when used with judgment it yields useful results with relatively simple analysis.

It is generally recognized, I believe, that even steady state stability is fundamentally a dynamic problem and that therefore the basic criterion for stable operation is that the various machines included in a system shall remain in synchronism after any change, such as a slow application of load, has been made. In view of this fact the various assumptions stated in this discussion apply only to the approximate, but practically the most useful, analyses in which inertia is neglected.

Power Limit of a Transmission System

Discussion of a paper by W. S. Peterson published in the August 1933 issue, p. 569–72, and presented for oral discussion at the power transmission session of the winter convention, New York, N. Y., Jan. 24, 1934.

Edith Clarke: Under "Fundamental Principles," Mr. Peterson states "A transmission system is essentially 2 groups of synchronous machinery, electrically connected together by a transmission line, . . ."; and, in the closing paragraph, "The method outlined in this article is one that enables an engineer without much special training in handling stability problems to obtain reasonably quickly solutions for the simple system which are quite accurate for all types of single location short circuits."

For the benefit of those "without much special training in handling stability problems," I would point out that the synchronous machines of transmission systems do not always swing in 2 groups during disturbances. In fact, they may swing in 3 or more groups depending upon the type of system and character and location of the disturbance.

When power is supplied from a generating station over long transmission lines to a load center which is also fed from nearby generators, or is equipped with synchronous condensers and a fault occurs on one of the transmission lines, the machines in the generating station probably will swing in one group and those in the load area in another group. If this be true, the system can be represented by 2 equivalent machines. This is the type of system shown in Fig. 2 of Mr. Peterson's paper and is the type of system and character of disturbance to which his method is applicable. However, should a fault occur between machines in the load area, the synchronizing torque between them might be so reduced that they would lose synchronism with each other, or one machine might lose synchronism with the others in the area. In this case, although the machines at the distant generating station would swing together, those at the load would not and the system could not be represented by 2 equivalent machines.

Two-machine methods are essentially time savers and are valuable as such. For any disturbance for which the machines of a system swing in 2 well defined groups, the error in replacing the system by 2 equivalent

machines is slight. Experience in stability calculations is an aid in predetermining the machines which will swing together. When such experience is lacking, it may be advisable to calculate the time-angle curves for the important machines or machine groups of the system for a typical operating condition and disturbance. Then, if the machines of the system swing in 2 groups, it reasonably can be assumed that they will swing in 2 groups for similar operating conditions and disturbances that are comparable.

A somewhat different method of applying the equal area criterion to short-circuit problems when the effect of resistance is taken into consideration is given in "Calculation of Two Machine Transient Stability With Resistance," by S. R. Pritchard, Jr., and myself. This article will appear in the February, 1934, issue of the *General Electric Review*. The angle between the machines at which the fault must be switched off in order for stability to be maintained is determined graphically. Then the time corresponding to this angle is determined by means of one time-angle calculation.

Cross Potential of a 4-Arm Network

Discussion of a paper by Anatoli C. Seletzky published in the December 1933 issue, p. 861–7, and presented for oral discussion at the electrical measurements session of the winter convention, New York, N. Y., Jan. 25, 1934.

W. B. Kouwenhoven: Seletzky presents a very simple and ingenious method of applying Schenkel's equations for the determination of the loci of the potential across the detector arm of a 4-arm bridge circuit. Seletzky, however, illustrates the application of his method with a bridge that is not commonly used in measurement work. In the bridge that he has used the center of the circle lies on a line connecting the e'_0 and e'_∞ vectors. This is not the case for all 4-arm a-c bridges. Here e'_0 is the value of the potential across the detector arm when the variable factor is taken as zero and e'_∞ the potential for the variable equal to infinity.

I have determined the loci of the potential across the galvanometer for both the series resistance and the Schering bridges. These 2 bridges give results that are similar in many respects; therefore I will present the data for only one of them.

Consider for example one of the commercial series resistance bridges shown in schematic form in Fig. 1. Here R_3 and R_4 are the ratio arms of 5,000 ohms each. The specimen under test is represented by its equivalent circuit, namely, the capacitor C_1 with its series resistance R_1. Assume that C_1 is 500 $\mu\mu f$ and that R_1 is 1,000 ohms. The variable arm contains the air capacitor C_2 and the resistance R_2. Since the bridge ratio is 1 to 1, $C_2 = 500\ \mu\mu f$ and $R_2 = 1{,}000$ ohms at balance.

Operating this bridge at 1,000 cycles holding C_2 constant at 500 $\mu\mu f$ and varying R_2 from zero to infinity, I find that the vector potential across the detector circuit for R_2 equal to zero is $e'_0 = 7.85 \times 10^{-4} \angle -90°$. When R_2 becomes infinity $e'_\infty = 0.5 \angle 0°$. At balance the galvanometer potential vector $e'_{\text{bal.}}$ is zero. These 3 points determine the circular loci of the potential across the galvanometer whose center, for R_2 variable, lies on the line connecting the e'_0 and e'_∞ points, as pointed out by Seletzky.

When R_2 is held constant at 1,000 ohms and C_2 is varied from zero to infinity, the e'_0 vector is found to be $0.5 \angle 0°$ and the $e'_\infty = 0.5 \angle 179°+$. Here as before the potential at balance is zero and it is evident that the vectors lie practically on the same straight line. The radius of the circle is very large in this case and its center does not lie on the line connecting the e'_0 and e'_∞ vectors.

It is evident from this analysis that in the series resistance bridge the vector potential across the detector produced by variations in the resistances is displaced 90 deg from that caused by changes in capacitance. It is also clear that over the normal operating range of bridge values of resistance and capacitance, not only are these vectors 90 deg apart, but also they are fixed in space. Therefore, it is possible to use a separately excited a-c galvanometer as a detecting instrument and to adjust the phase of its field excitation so that it will respond to a variation in either resistance alone or capacitance alone. This conclusion is borne out by experimental proof (see "A High Sensitivity Power Factor Bridge," W. B. Kouwenhoven and A. Banos, Jr., A.I.E.E. Trans., v. 51, 1932, p. 202–10).

The determination of the points for the loci of the detector circuit potential also brings out another interesting fact concerning the relative sensitivities of the 2 balance operations. For example, the change in the resistance R_2 from zero to its balance value of 1,000 ohms produces a change in the potential across the galvanometer of only 7.85×10^{-4} volt per volt applied to the bridge; whereas the change in capacitance C_2 from zero to balance at 500$\mu\mu f$ causes a change in galvanometer potential of 0.5 volt per volt.

Portable Schering Bridge for Field Tests

Discussion of a paper by C. F. Hill, T. R. Watts, and G. A. Burr published in the January 1934 issue, p. 176–82, and presented for oral discussion at the electrical measurements session of the winter convention, New York, N. Y., Jan. 25, 1934.

J. C. Balsbaugh: I think this paper gives a very interesting application of the Schering bridge. I should like to ask the particular reasons for using the inverted type of Schering bridge inasmuch as the more general type also would be applicable. The more general type of Schering bridge may be used with one of the bridge arms at ground potential and then balancing the shield-to-ground potential. The advantages of this method would be that it would maintain the measuring and balancing resistances and capacitances at close to ground potential. Furthermore, in this case the lead from the

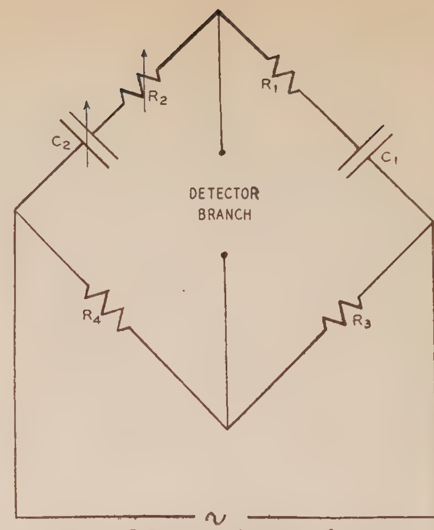


Fig. 1. Schematic diagram of a commercial series resistance bridge

bushing being tested to a disconnecting switch will be at a point common to the 2 halves of the bridge and therefore will not introduce difficulties in the bridge measurements similarly to the case of the inverted Schering bridge where this lead from a bushing is connected to one of the bridge arms, and therefore electrostatic pick-up in this lead being included in the bridge measurements.

I should also like to obtain the sensitivity of the bridge expressed as that change in power factor from balance which will give, say, 1 mm deflection of the galvanometer for certain specified bridge constants and applied voltage.

With respect to the use of power factor as a criterion of the condition of insulation in general, I think it would be better to use some value that would be directly proportional to the in-phase component of current and would be independent of capacitance. This method would give a more accurate indication of the condition of an insulation and would be more applicable for direct comparative purposes. In general, of course, power factor is not in independent of a change in capacitance and furthermore is not directly proportional to the in-phase component of current when the power factor exceeds 0.05 to 0.10.

Eugene D. Eby: The measurement of power factor constitutes one means of comparing insulating materials of dissimilar character and also the effects of varying conditions upon the same or similar classes of insulations. Power factor measurements on apparatus in service may add materially to the sum total of our knowledge of the various insulating materials, as well as disclose the effects of service conditions upon such materials commonly employed in electrical equipment.

It is generally recognized that the absolute value of the measured power factor of a particular insulating material, as compared with similar measurements of other materials, constitutes in itself no basis for comparing its suitability for its use in a particular field to the suitability of other insulations in their respective fields. In other words, the absolute value of the power factor means very little, since different insulations

vary widely in power factor while performing their functions with equal success. In fact, a value of power factor that would be considered entirely normal for one material could be accepted as sufficient evidence of unreliability for another. For example, a certain filling material for bushings having a normal power factor at 25 deg C of 0.001 would be immediately condemned at a power factor of 0.02 which is the normal value for certain grades of resin treated paper.

It becomes apparent, therefore, that with widely varying values of power factor for different insulating materials a composite structure employing several such materials will show a power factor intermediate of the maximum and minimum values represented and dependent upon the relative amounts and disposition of the various materials employed. Thus, a bushing the insulating material in which is largely resin treated paper will have an over-all power factor approaching the value for this material, whereas, a bushing employing low power factor oil to a large degree will naturally have an over-all power factor much lower than the paper bushing. For these reasons, each type of bushing, and even each size of a given type (for the proportions of widely different materials vary appreciably) will have a normal characteristic power factor of its own. An intelligent use of power factor measurements must recognize these varying normal values.

The effect of service conditions upon the power factors of different insulating materials may be widely different also. This fact even may obscure the presence of danger in a composite structure, as, for example, when a sparingly used material, which contributes very little to the over-all power factor of the composite structure, experiences a serious increase in its own power factor without appreciably affecting the whole.

The best guide for determining the significance of a power factor measurement is a comparison with previous measurements under the same conditions or with known standards. For this reason, complete records of all measurements should be placed on file for future reference and for comparison with new readings as obtained.

Because of the great variation in bushing design, and in the characteristics of the materials employed, as well as the varying effects of service conditions upon these different designs and materials, a great amount of data will be required before any strict limits can be set for power factor values beyond which operating reliability is definitely impaired. It is likely that such limits will vary widely for different types of bushings. For example, bushings using only solid materials, some of which have their electrical properties greatly affected by moisture, may require a comparatively low limit of power factor beyond which they should be removed from service; on the other hand, it may be found that bushings employing a liquid filler which allows moisture to settle out in time, or causes it to rise to the surface can be given a higher limit, since with continued operation their condition would tend to improve.

Because of the widely varying effect of temperature upon Power Factor values, any established limits must be related to a definite temperature or be expressed in the form of temperature vs. power factor curves. The effect of temperature varies widely with different materials as illustrated in Fig. 2.

Consequently, the temperature—power factor characteristics of different types of bushings will be different, depending upon the materials of which they are composed. This is illustrated in Fig. 3.

The effect of change in the testing voltage upon the power factor value is also different with different materials, and consequently, with different combinations of materials. While dry type bushings generally have a rising characteristic, bushings of the liquid filled type may have a falling characteristic as illustrated in Fig. 4. Fortunately, experience indicates that for field purposes a test potential of from 10,000 to 20,000 volts is adequate for indicating the general condition of a bushing.

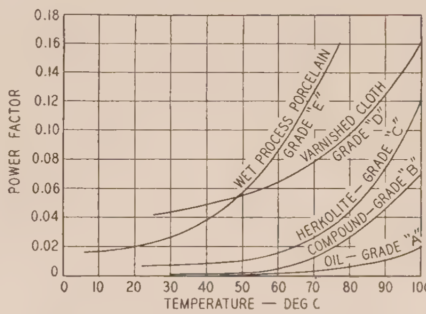


Fig. 2. Variation of power factor with temperature, for representative bushing materials

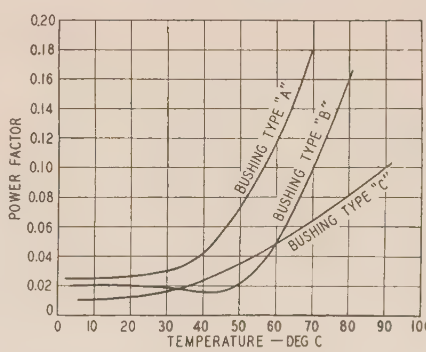


Fig. 3. Variation of power factor with temperature, for several types of bushings

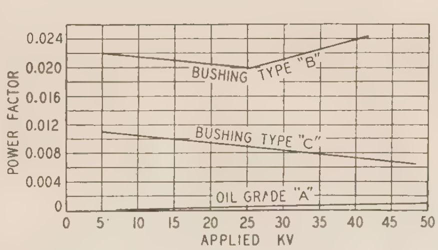


Fig. 4. Variation of power factor with voltage, for 2 types of bushings using liquid fillers

Everett S. Lee: The very interesting paper by Hill, Watts, and Burr and the admirable papers by Gross and Turner, published in the January 13 and January 20 issues of *Electrical World* on "Testing Bushings and Insulation by Power-Factor Method" in which results of field tests on some 10,000 bushings are reported, bring before us the time-honored subject of the determination of the quality of electrical insulation. That this is not a new subject, the oldest ones among the readers will attest. I know from the literature that it started long before my time and I know from experience that it is not yet solved.

Some 9 years ago there was delivered from this platform a paper ("Testing High-Tension Impregnated Paper-Insulated Lead-Covered Cable," by Everett S. Lee, A.I.E.E. TRANS., v. 44, 1925, p. 104) on the testing of cables which, with the ensuing discussion, included almost every ramification of the subject known at that time; and a year later the classic papers of Roper and Halperin ("The Quality Rating of High-Tension Cable With Impregnated-Paper Insulation," A.I.E.E. TRANS., v. 44, 1926, p. 528) and Farmer ("Tests of Paper Insulated High-Tension Cable," A.I.E.E. TRANS. v. 45, 1936, p. 553) were presented at Madison, Wis., suggesting ways in which the quality of insulation might be definitely evaluated. It was brought out at this time that our knowledge of the mechanism of the breakdown of insulation had not been brought to a point allowing definite evaluation to be carried on with certainty.

The subject has since been consistently studied for all classes of apparatus and all kinds of insulation, but the answer today is much the same.

From all of our experience certain empirical tests applied in this way or in that way have served to show that new insulation was in such condition that the apparatus could be used safely and the life to be expected therefrom under known operating conditions would be satisfactory. In each case there is a safety factor sufficient to provide for obtaining the desired result. As insulation is used and becomes subjected to not only usual but sometimes unusual operation conditions, the same tests are generally applicable although the limiting values may change.

So it is with bushings. It is generally accepted that measurements of insulation resistance and power factor obtained by any accepted means, of which there are several give data that allow of discussion relative to the quality of the insulation at the time of the measurement. In general, insulation resistance is the most sensitive test for detecting the presence of moisture; but for the various forms in which deterioration is manifest, I believe it is generally felt that power factor results are of the greater usefulness. As time goes on the measurement of other properties may be found appropriate; but it is the interpretation of the measured values into terms of quality of insulation which is the most difficult part of the whole problem and the one which presents the greatest uncertainty. The more data that are obtained under the same general conditions, the greater the certainty of the interpretation; but it is still true that with our present knowledge the limiting values that may be set, although helpful, are not all-conclusive nor certain to such a degree that the job can be considered wholly perfect.

It is not a difficult matter to measure the power factor of a bushing in the field either by a bridge method, such as described by Hill, Watts, and Burr, or by the wattmeter voltmeter-ammeter method described by Gross and Turner. The real difficulty comes in assigning limiting values representative of

quality conditions and to do it with certainty. The more of this work that is done, however, the greater will be our ability to use whatever information we have for good.

F. L. Moser and H. B. Wolf: The paper by Hill, Watts, and Burr is of especial interest to operating men responsible for the maintenance of apparatus and continuity of power service.

The management of the company (Duke Power Company) with which we are associated has considered the development of equipment suitable for testing bushings to be of great importance. We therefore have long been experimenting with various devices. Early in 1930 after many tests the equipment that we now use proved satisfactory. As our experience indicates the great value of bushing testing in reducing failures, with consequent reduction in interruption to power service, we are presenting herewith a brief description of our equipment with a summary of results obtained.

In making this test we apply an a-c potential of 33 kv to the bushing under test and read the current flow through the combined capacitance and resistance of the bushing. The equipment used consists of a motor-driven 100-watt 110-volt single-phase alternator for supplying a fixed wave shape and voltage to the step-up transformer, which has a ratio of 110 to 30,000 volts, a milliameter with current transformer, and an a-c voltmeter, together with necessary

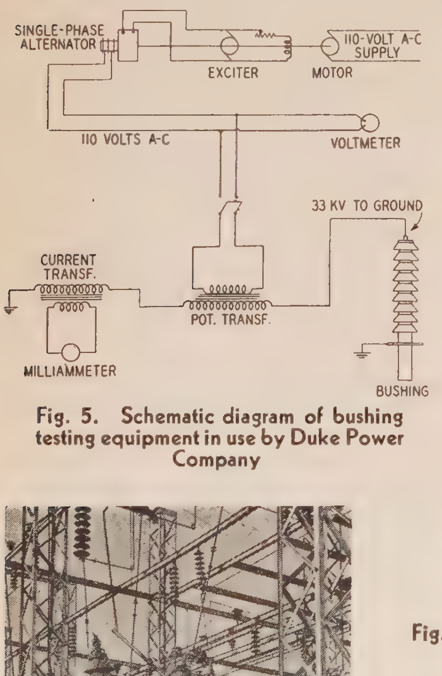


Fig. 5. Schematic diagram of bushing testing equipment in use by Duke Power Company

Table I—Summary of Tests on Oil Circuit Breaker Bushings

Year	Rated Kv	No. of Breakers	No. of Tests Made
1930	100	214	2,556
	44	8	60
1931	100	233	4,344
	44	40	264
1932	100	241	2,886
	44	48	546
1933	100	209	2,334
	44	40	426
Total bushing tests, 100 kv			12,120
44 kv			1,296
Grand total			13,416

leads, etc. (See Figs. 5, 6, and 7.) The milliampere reading is recorded as well as the temperature at the time of test. If the reading obtained is above the known average for the type and voltage of the bushing under test, and if the reading is not reduced by cleaning, the bushing is removed to the shop, dismantled, and, if possible, repaired. The lift rod and guide assembly is tested by applying potential to the bushings with the breaker closed.

Defects in bushings of the oil filled, condenser, and compound filled types manufactured in the United States and abroad have been located by this equipment and have been successfully repaired locally. A service record is kept of these repaired bushings and only one has failed from August 1932, to date. Table I shows a summary of tests made.

In the year 1933, 68 100-kv and 10 44-kv defective bushings were located and all but 2 100-kv were repaired locally and again put in service.

A comparison of service records for 1930 and 1933, that is before and after the development of this method of test, is shown in Table II. Lightning storms in this vicinity were not unusually severe during either year. The U. S. Weather Bureau recorded 45 storm days in 1930 and 57 in 1933; the 10-yr average is 51.8 storm days. As the voltage (33 kv) impressed on the bushing is over half of the line to ground voltage of the 100-kv bushings and somewhat over the line to ground voltage of the 44-kv bushings, the readings give a very positive indication of the condition of the bushings.

Approximately 2 months is required to make a routine test of the 250 breakers normally tested. Two men travelling in a light coupe are used; the equipment is compact and light enough to be carried in the rear compartment of the car. Approximately

Fig. 6 (left). Making a field test on a 100-kv oil circuit breaker bushing

Fig. 7 (below). Complete bushing testing equipment used by Duke Power Company

Table II—Failures of Oil Circuit Breaker Bushings During 1930 and 1933

	1930	1933
100-kv bushings in service	1,446	1,470
100-kv bushing failures in %	1.73	0.61
44-kv bushings in service	1,260	1,260
44-kv bushing failures in %	2.22	0.40
Total bushings in service	2,706	2,730
Total bushing failures in %	1.96	0.47

4,000 miles are travelled in making a routine test.

We agree with the authors that the majority of bushing troubles are due to moisture entering the bushing. It is not uncommon for 1 lb of water to be evaporated from a 100-kv bushing which has been in service several years. Due to the improvement in design and construction, the newer type bushings do not absorb moisture to the extent of the older types; however, a number of the newer type have been found defective.

A limited number of transformer bushings have been tested. As the percentage of transformer bushing failures is small compared to oil circuit breaker bushing failures, the improvement resulting from transformer bushing tests cannot be expected to yield as noticeable results as in the case of breaker bushing tests. However, these tests are well worthwhile where the service from transformers is of vital importance or where service records indicate deterioration of bushings.

H. H. Spencer: The maintenance of apparatus bushings, particularly oil circuit bushings, has been a problem that has long occupied the attention of operating engineers. In The New England Power System we have made use of the megger for 15 years as an aid to determining when bushings should be removed from service. This instrument has been used with increasing success as experience has improved the technique of the operating personnel.

In 1928 the New England Power System commenced studying the conditions of bushings by means of field measurements of dielectric loss. The method used was devised by the Doble Engineering Company and was a modification of their equipment which previously had been used in testing pin type insulators. The test equipment consists of direct reading voltmeters, ammeters, and wattmeters measuring the total current and power in the bushings being tested under an applied voltage of 10,000 volts, rms, 60 cycles.

Our success with this type of test has been much better than with the 1,000-volt megger; but the success of this method or any other method which depends upon the measurement of resistance, leakage current, or dielectric loss rests entirely upon the experience of the operator in making the tests and the judgment of the engineers in interpreting the results. The fundamental characteristics that the bridge presented by the authors of this paper, or the apparatus we have used, detects, is change. Inherently a bridge probably can detect smaller changes in power loss than the wattmeter can. Practically, the casual differences in testing technique due to leads, etc., may introduce greater errors than the inherent difference in

precision between the bridge and the wattmeter. In any case the major problem is for the engineer to decide how much change he can tolerate in the dielectric loss or power factor of a particular bushing before it is necessary to remove it from service.

There can be no question as to what constitutes a desirable specification for an oil circuit breaker bushing. Its external flashover voltage should be less than the internal flashover or puncture voltages, and it should be greater than the discharge voltage of adjacent protective devices such as spillway sections of transmission lines, coördinating gaps, or lightning arresters. During the past few years, the characteristics of insulators have been studied with increasing care and the suggestion has been made that station and line insulation be coördinated within fairly close tolerances.

However easy it may be to install new apparatus so that the insulation will be properly coördinated, there exists at present only one means of determining whether insulation that has been in service for some time is still coördinated properly—the high potential test both at normal frequency and under impulse. Such tests are difficult to perform in the field; but even more important is the fact that so many bushings would be severely damaged by the high potential testing that the replacement cost would be prohibitive. It appears that a station design using fairly wide tolerances of insulation coördination, plus a testing technique involving indirect measurements backed up by experience and comprehensive test records on each individual bushing, will have to be the ultimate answer to this problem.

Heavy Surge Currents—Generation and Measurement

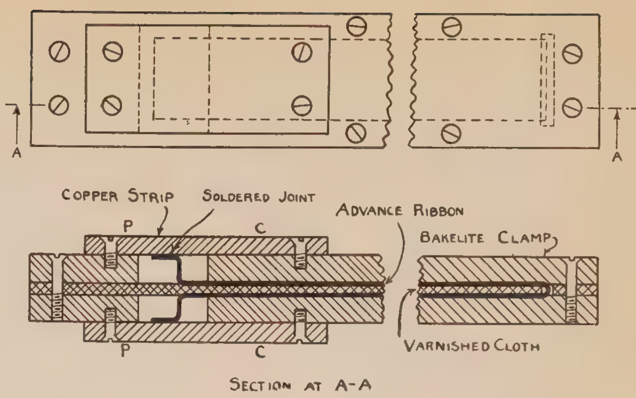
Discussion of a paper by P. L. Bellaschi published in the January 1934 issue, p. 86–94, and presented for oral discussion at the electrical measurements session of the winter convention, New York, N. Y., Jan. 25, 1934.

Theodore Brownlee: Means for producing and measuring heavy surge currents have been developed in the lightning arrester research laboratory of the General Electric Company in Pittsfield along much the same lines as outlined in Mr. Bellaschi's paper, and we are in general agreement concerning the precautions and requirements necessary to obtain good results.

Except for the sake of economy, an impulse generator built for millions of volts is not adapted for heavy current work. The spacings used for clearance between individual capacitor tanks, and between the tanks and ground, add unnecessary inductance to the circuit. As stated by Mr. Bellaschi, low impedances are needed throughout, meaning a large capacitance and low inductance and resistance. The capacitors should be carefully designed, and if roll wound, many taps brought out to secure low internal resistance and inductance. Usually it is necessary to use the same capacitors for high voltage and high current work, so that low voltage high capacitance units are not available. At any rate, the available capacitors should be connected all in parallel with tanks as close together as possible. A convenient arrangement is to mount 2 rows of capacitors, one above the other, with the upper row upside down so that all may be connected to 2 parallel busses mounted on the capacitor bushings. Busses of large copper tubing minimize the inductance. The load should be connected to the midpoints of the 2 parallel busses. If a very large number of capacitors is to be used with a minimum of inductance, several double rows should be spread out from the load much the same as the elements of shunt B in Fig. 11 of the author's paper.

Fig. 8. Low inductance shunt for impulse measurements

Current clips at C-C
Potential clips at P-P



The methods outlined in the preceding paragraph are for obtaining the highest possible current from a given number of capacitors. Such effects as the fusing of conductors depend only upon the energy available, and it is immaterial whether there is considerable inductance in the circuit or not, since in a series circuit all the energy must be dissipated in the resistance load.

It is convenient when making an experimental study of the heating effects of impulses to have aperiodic waves, as the analysis of the oscillograms is much simpler. To secure such waves less additional resistance is required with low inductances. Thyrite is admirably adapted to render high current waves nonoscillatory, for it has low resistance at high currents and increased resistance at low currents. Hence, with a given capacitance voltage and inductance, a higher and more symmetrical aperiodic current wave can be obtained by using thyrite. Examples of such waves were shown about 2 years ago in an article on the blowing of fuses by impulses. ("Impulse Characteristics of Fuse Links," E. M. Duvoisin and T. Brownlee, *General Electric Review*, May 1932, p. 260–6.)

The study of high currents is almost of necessity tied up with the study of more moderate currents of very short duration, for in both, shunts of very small time constants, L_s/R_s, are required. At the time of the fuse-blowing tests, the problem of producing reliable shunts of low time constants was attacked both experimentally and by calculation. The best arrangement found is illustrated in Fig. 8 where an extremely thin ribbon of advance of manganin metal is doubled back and tightly clamped together with a very thin layer of insulation between. In this manner the outgoing and incoming current paths nearly coincide, and the inductance, while calculable, is almost impossible to detect by experiment. In Fig. 9 is reproduced Fig. 3C of the fuse-blowing article previously mentioned, showing one of the faster waves recorded by this type of shunt.

A shunt was made up similar to a single element of the shunts shown by the author in Fig. 11 and having the same resistance as our shunt of 0.474 ohm. A 20-in. length of No. 20 B. & S. gauge manganin wire was used making a twisted loop 10 in. long.

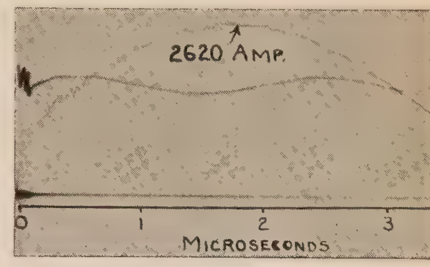


Fig. 9. Cathode ray oscillogram of a 4.8-μ sec wave (16.8 amp^2 sec) recorded by means of a shunt of the type shown in Fig. 1

The insulation thickness was about 0.002 in. giving 0.036 in. between centers and 0.032 in. conductor diameter. Copper leads were soldered on and brought out at right angles to the shunt element and the manganin wires carried on noninductively for about 2 in. where they were connected to our customary shunt cable.

The inductance was assumed to be the same as for 2 parallel conductors and calculated by the well known formula:

$$L = 0.004l\left[2.303 \log_{10}\frac{2D}{d} - \frac{D}{l} + \frac{\mu}{4}\right]$$

where

L = inductance in microhenries
l = length of each wire in cm
D = distance between centers in cm
d = diameter of wires in cm

The calculated inductance is 0.107 μh giving a time constant L_s/R_s = 0.226 μsec

Our 0.474-ohm shunt was made of 23 in. of advance ribbon 0.25 x 0.004 in., doubled back with one layer of varnished tape 0.01 in. thick for insulation.

The inductance is calculated by the formula:

$$L = 0.00921[(d^2/b^2)\log d + 0.5(1 - d^2/b^2)\log(b^2 + d^2) + 0.8686\, d/b \tan^{-1} b/d - \log b]$$

where

d = distance between centers of tapes in centimeters

l = length of loop in centimeters = $^1/_2$ length of tape
b = breadth of tape in centimeters
L = self-inductance of shunt in microhenries

Common logarithms used.

This formula is a combination of formulas 117 and 132 of Bureau of Standards *Scientific Paper 169* (Rosa and Grover, Formulas for the Calculation of Mutual and Self-Inductance, *Bulletin* of the U.S. Bureau of Stds., v. 8, No. 1, Jan. 1911).

If we let $b/d = x$ there is obtained:

$$L = 0.00921l \left[\left(\frac{x^2 - 1}{2x^2} \right) \log (1 + x^2) + \frac{0.8686}{x} \tan^{-1} x - \log x \right]$$

showing that the inductance depends only on the length and the ratio $X = b/d$.

Also it is found for the cases where the ribbon width is large compared to the thickness of the ribbon or insulation, that the inductance is very nearly proportional to the parameter ld/b, so that for a given thickness of ribbon and insulation, the inductance and resistance are proportional, and the time constant L_s/R_s is fixed. Hence, the length and width of ribbon required for a particular shunt is determined by temperature considerations. The change in resistance of "advance" materials is less than $^1/_2$ of 1 per cent for all temperatures up to 400 deg C.

For the 0.474-ohm "advance" shunt the calculated inductance is 0.0194 μh giving a time constant of 0.041 μsec.

In order to show the distortion produced by these 2 shunts, the dotted lines of Fig. 10 give the shunt voltage that would be produced on each with the passage of the 2,620-amp current surge shown in Fig. 2. These are to be compared with the solid line which is based on a shunt of no inductance. It is very evident that the lower inductance ribbon shunt gives a much more faithful representation of the true current wave shape. However, the discrepancy is more a change in phase than of magnitude, and unless very extended time scales are used on the oscillograms, it is difficult to detect the errors by simple oscillographic comparison of current-time waves.

One good method to detect the inductance of any particular type of shunt is to construct a counterpart using copper wire in which the inductance voltage will predominate because of the greatly lowered resistance. A simpler method and the one we use to judge our shunts is to record the volt-ampere curve of a noninductive resistance such as a short thick water column or stack of thyrite. Then, unless the recorded voltage and current are in absolute phase, a loop will appear in the characteristic. Figure 11 shows 2 volt-ampere curves taken on the same stack of thyrite disks using the same impulse circuit and the 2 0.474-ohm shunts. The impulse used was slightly slower than shown in Fig. 10, rising to a crest of 3,800 amp in 3.0μsec and dropping to half value in 6.8μsec. In spite of this fact, the loop is very pronounced with the twisted wire shunt and imperceptible with the ribbon shunt. The physical explanation of the superiority of the ribbon shunt in this particular case is the fact that the outgoing and returning current paths are closer together. If, instead of a single element of No. 20 wire, a large number of elements of fine wire were put in parallel, the time constant would be reduced, but at the expense of making a rather intricate and delicate shunt.

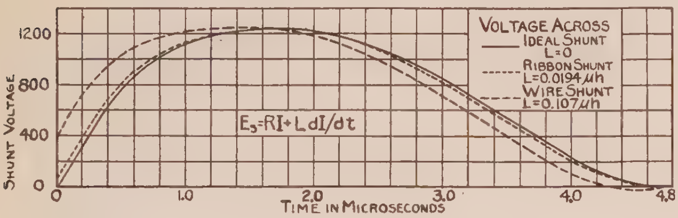


Fig. 10. Calculated effect of inductance in 0.474-ohm shunts

The conclusions to be gathered from the foregoing paragraphs are applicable to the measurement of as high currents as can be produced. It is only necessary to use wider ribbon and perhaps, spread a few elements in parallel as is done by the author. Shunts of somewhat smaller time constants than 0.0194 μsec can be made by using thinner ribbon and very thin mica insulation. The use of higher resistance alloys, such as nichrome, decreases the time constant, but nichrome is difficult to solder to the current leads, and has a considerably higher temperature coefficient than advance or manganin.

A method for compensating for the inductance of 4 terminal resistances has been described by F. B. Silsbee ("Notes on the Design of 4 Terminal Resistance Standards for Alternating Currents," Bureau of Standards *Journal of Research Paper No. 133*, v. 4, No. 1, Jan. 1930) but such refinements seem hardly necessary for the fastest laboratory waves now used. The same paper also shows some experimental data by which the skin effect of ribbon shunts may be calculated at low frequencies. There seems to be few available data concerning skin effect for conductors at close spacings and high frequencies. If we assume the low frequency formulas are approximately correct at high frequencies, it is found that skin effect can be disregarded in both types of shunts and all of our experience substantiates this conclusion. The capacitance between the shunt conductors with either type of shunt is entirely negligible. For instance with the 0.474-ohm ribbon shunt the total capacitance between ribbons is (assuming $K = 4$) 214$\mu\mu f$ giving a time constant $R_s C_s$ of about 0.0001 μsec.

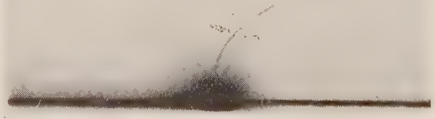


Fig. 11. Volt-ampere characteristic of a stack of thyrite disks measured with 0.474-ohm wire shunt (above) and 0.474-ohm ribbon shunt (below)

J. L. Thomason: In Appendix III of his paper, Mr. Bellaschi gives the derivation for the current required to fuse copper wire with an applied exponential wave. It is interesting to note that similar calculations were made by Mr. Peek about 4 years ago in his 1930 paper "Lightning" (A.I.E.E. Trans. v. 50, p. 1077–89).

Bellaschi based his calculations on an exponential current wave specified in terms of the time T to 50 per cent of crest current, that is

$$i_1 = I\epsilon^{-0.69t/T}$$

The energy associated with this wave is

$$H_1 = r \int_0^\infty i_1^2 \, dt = \frac{r I^2 T}{1.38}$$

Peek based his calculations on an exponential current wave specified in terms of the time T_1 to 5 per cent of crest current,

$$i_2 = I\epsilon^{-3t/T_1}$$

And the energy associated with this wave is

$$H_2 = r \int_0^\infty i_2^2 \, dt = \frac{r I^2 T_1}{6}$$

Therefore for waves of equal crest and energy $H_1 = H_2$ or

$$T = \frac{1.38}{6} T_1 = 0.23 \, T_1$$

Consequently, expressing Bellaschi's current equation in terms of T_1 instead of T, there is

$$I = 320{,}000 \frac{A}{\sqrt{T}} = 660{,}000 \frac{A}{\sqrt{T_1}}$$

as compared with

$$I = 510{,}000 \frac{A}{\sqrt{T_1}}$$

from Peek's curves. The constant terms are at least of the same order of magnitude.

I should like to ask Mr. Bellaschi what specifically was learned about lightning phenomena by these high current tests? How was the current distributed in the cross section of the arc? This point may have an essential bearing on the calculation of the inductance and surge impedance of a lightning stroke. How long did the path remain ionized? This point may have an important bearing on the question of repeated strokes.

Simultaneous Control of Voltage and Power Factor

Discussion of a paper by L. F. Blume and F. L. Woods published in the December 1933 issue, p. 884–9, and presented for oral discussion at the electrical machinery session of the winter convention, New York, N. Y., Jan. 25, 1934.

A. Boyajian: During the past few years, I have been very much impressed by the strong tendency in the electrical industry to give preference to static equipment as exemplified in the rapid growth of power rectifier installations in competition with synchronous converters. The static equipment generally is far more efficient, very quiet, requires minimum maintenance, and lends itself most conveniently to automatic operation with remote control. Now, L. F. Blume and F. L. Woods call attention to another field in which static equipment may come to play an equally prominent part, extending into fields dominated in the past by the synchronous condenser.

I have had the privilege of discussing this paper with the authors previously and have found out that their major proposition is not so much the replacement of one kind of equipment by another as it is the proposition that power factor correction and voltage control should not be considered as separate problems and treated by different specialists; they should be treated and solved as one problem with proper regard to both aspects of the problem. In the past, when power factor was the major consideration, capacitor engineers generally solved the problem. In general there was some improvement in voltage regulation also, but this was only incidental and not very satisfactory. When voltage regulation has been the major thought, either synchronous condensers or tap changers have been utilized in the circuits of higher power. Here again, the power factor is unaffected or, if affected, it is incidental and subservient, and best results can never be obtained. The thesis of the authors' present paper is that by proper combination of equipment for both voltage regulation and power factor correction, each part of the equipment is utilized for the type of service and in the range in which it is most effective, and the resulting benefits are maximum.

In line with the foregoing, the authors also believe that there may be suitable applications for the synchronous-condenser-tap-changer combination as well as the capacitor-tap-changer combination. Whatever may be the cost comparison between the static equipment and the rotating equipment at the present moment, it is a significant fact that capacitor cost curves, even after correction for the changes in the industrial price level, have been sloping downward for several years, and one may venture to predict that this will continue for some time to come, making the static equipment for simultaneous control of voltage and power factor increasingly more attractive.

L. M. Olmsted: This paper presents an extremely interesting and convenient method for solving the various problems arising in connection with the application of shunt capacitors or synchronous condensers to regulate voltage. Also, the scheme by which the effective shunt capacity in the combined equipment is varied seems most ingenious, and reduces the equipment to a minimum.

The device has limitations, however, which may seriously restrict its application on power systems. In order to control voltage most effectively by improving the load power factor it is necessary to locate the capacitors at the load center so that the voltage drop in the supply system may be reduced by the neutralization of reactive current. On distribution feeders, for example, which are commonly regulated by means of individual regulators at the substation, it seems probable that locating such regulating equipments at the several load centers would prove undesirable. The most likely application would seem to be for bus regulation in substations, where it might replace the present regulating equipment.

Wide acceptance of such a device depends, of course, upon economic justification. The paper suggests this and presents a comparison of relative losses. A valid comparison can be secured, however, only by analysis of the investment involved for the several equipments, the operating expense, and the losses properly evaluated to include charges for the supply system. Such a comparison indicates that the addition of capacitors usually will not reduce the cost of regulating distribution feeders and suggests that even for substation bus regulators there will be many situations where the capacitors cannot be justified.

It is recommended that the analysis begun in the paper be extended to disclose for the guidance of the industry the conditions for which the combination of voltage and power factor control can be justified.

Effects of Rectifiers on System Wave Shape

Discussion of paper by P. W. Blye and H. E. Kent published in the January 1934 issue, p. 54–63, and presented for oral discussion at the electrical machinery session of the winter convention, New York, N. Y., Jan. 25, 1934.

J. J. Smith: This paper by P. W. Blye and H. E. Kent gives a useful method of estimating the effect on the wave shape when a rectifier is operated on an a-c system. The data given show that their formula has been checked with calculation in several cases, and the agreement generally is within ±20 per cent which is sufficient for such calculations. The authors also give a brief review of the results that may be expected from the resulting harmonics in the wave shape.

Their method consists in assuming that the valve action of the rectifier in cutting off the current in successive anodes can be replaced by an equivalent harmonic voltage in the circuit. In a paper by H. D. Brown and J. J. Smith (Trans., A.I.E.E., v. 52, Sept.-Dec. 1933, p. 973) we approached the problem from the other point of view, namely that of determining the effect of the inductance of the circuit in modifying the currents under load. We have used both types of calculation in a number of cases and it may be of interest to state that on the average they agree within better than 20 per cent. In one isolated case the difference between the results was 75 per cent, but no opportunity was available to test which method gave the better practical result since the installation was only a projected one. The impedance diagram of the system in the latter case was a very complicated one with several resonance points.

In calculating any given installation there are 2 points at which discrepancies may arise: (1) in the estimate of the impedance of the system; (2) in the use of the authors' formula. I should like to get an idea of the authors' experience as to the relative magnitude of the per cent error which might be expected due to these 2 causes; that is, given the measured impedance, what accuracy can we expect and how much additional error may be introduced when we have to estimate the system impedance.

Usually it is more important that the result of calculation be correct for the case when the rectifier is fully loaded than for the case when the rectifier is lightly loaded. Can we assume roughly in connection with the curves in the authors' Fig. 3 that the lower values correspond to full load approximately?

I should like to suggest in connection with the authors' Fig. 10 that if actual values for a typical case were added it would materially enhance the paper since it would enable any one working a problem to check his method of calculation on a standard case. Possibly the authors could add such a diagram in the discussion.

Under the heading "Power System Factors Affecting Wave Shape" on page 61 (Elec. Engg., Jan. 1934), reference is made to the effects to be expected on large systems and in cases where high voltage supply lines are used. It is important to remember that the distortion in voltage is a function of the impedance of the system. If we connect a rectifier to a large system through a considerable amount of reactance, the resulting distortion at the terminals of the rectifier may be as large as if it were operated from a small system. Thus some of these statements, while in general correct, might lead to errors if they are taken too literally.

On page 61 the reader is referred to the Report of the Joint D. & R. Subcommittee of the E.E.I. and Bell System for other coordinative measures. In those reports the various measures are scattered through several volumes. I believe that a paper before the Institute describing these methods and giving an outline of the effects to be expected from them would be a valuable contribution to the literature and would be of considerable assistance in practical studies.

R. F. Davis: In the usual field case involving a consideration of the inductive coordination of telephone circuits and a-c feeders supplying rectifiers, preliminary calculations of the order of magnitude of the noise to be expected serve as a valuable guide. While such noise computations are not an adequate substitute for actual measurements, often it is not practicable to make sufficient measurements in the early stages of the project to determine accurately what the noise will be. In such cases, the

results of computations made during the planning stage of the project permit an orderly program of study of those cases where the calculations indicate a potential noise problem. Prominent in such a preliminary review is the consideration of rearrangements which might readily be made in the two services and which would materially reduce the likelihood of excessive noise. Also consideration may be given to the other methods of coördination referred to by the authors.

The noise estimates require data not only regarding the power system characteristics, but also with respect to the coupling and telephone plant, so that it is evident that a high degree of accuracy in the calculations is unlikely. Since the methods of computing one of the factors described by P. W. Blye and H. E. Kent materially narrow the range of error involved, their value in the over-all noise calculations and in inductive coördination work is evident.

Equivalent Reactance of Synchronous Machines

Discussion of a paper by S. B. Crary, L. A. March, and L. P. Shildneck, published in the January 1934 issue, p. 124–32, and presented for oral discussion at the electrical machinery session of the winter convention, New York, N. Y., Jan. 25, 1934.

J. W. Butler: In reading this paper one gets the idea that this proposed equivalent reactance would be a very difficult one to use. There are given 3 equations (5, 6, 7), for the equivalent reactance of a cylindrical rotor machine, and 2 equations (9, 10), for the salient pole machine. These equations refer to the value of equivalent reactance to use under different operating conditions such as power factor and voltage. Also Figs. 8 and 11 are given showing the equivalent reactance of the machine as a function of the external impedance. These figures show a very wide range of reactance. For instance, Fig. 8 varies from 0.4 to 1.2 for a cylindrical rotor machine and Fig. 11 varies from 0.41 to 0.95 for a salient pole machine. Thus it appears without further study that the value of equivalent reactance is very critical to power factor, voltage, and the external impedance connected.

Fortunately, this picture is not as bad as it seems. Referring to Fig. 11, it is seen that the equivalent reactance of a salient pole machine for all values of external impedance, having a ratio of resistance to reactance of from 0 to 0.75, varies only 10 per cent. This range of the rating of resistance to reactance is certainly much greater than will be met in practice. Thus for a salient pole machine, operating under a constant voltage back of leakage reactance (constant flux loading) the equivalent reactance is found to be substantially constant and is not affected much by the power factor, terminal voltage, or the connected external impedance.

This enables a test to be made for the equivalent reactance of the salient pole machine under a condition other than that under which it is to be operated, but with

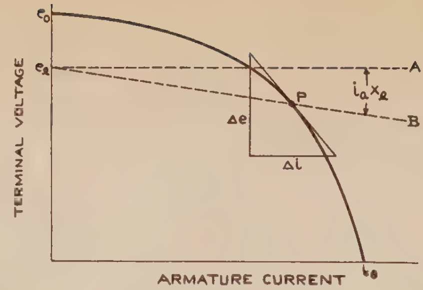


Fig. 1. Voltampere characteristic of a synchronous machine with constant field current at zero power factor

the same flux loading. For the salient pole machine the zero power factor test is the only one that can be simply made for the determination of the equivalent reactance. From this test, the equivalent reactance is obtained in accordance with eq 18. Consequently, if the test is made with the machine at zero power factor and the equivalent reactance measured at the point of the voltampere characteristic where the voltage back of leakage reactance is the same as it is when the machine is operating under normal operating conditions with the same field current, a reactance is obtained that corresponds very closely to the value under normal conditions.

The voltampere characteristic of a synchronous machine with constant field current at zero power factor has the general shape shown by the curve Fig. 1 of this discussion. This curve is easily obtained from test as follows: The point of zero current is obtained by reading the open circuit voltage e_0 with normal field current, and the point of zero voltage is obtained by reading the short circuit current i_0 with normal field current. Intermediate values are determined by operating the machine as a synchronous condenser from a power source in which the voltage may be varied. The field current is held at a constant value for the entire range corresponding to normal full load field current. The determination of the location of point P in Fig. 1, which is the point at which we are to measure the slope for determining the equivalent reactance is as follows:

Line A is drawn from the calculated value of e_l (voltage back of leakage reactance) for the full load normal operating condition, the internal drop from e_l to the terminal voltage is $i_a x_l$. Hence line B is drawn having a displacement from e_l equal to $i_a x_l$. Thus, the intersection of B with the voltampere curve at P gives a point at which the zero power factor machine is operating with the same internal voltage (or flux loading) as it would under normal conditions, and the equivalent reactance is

$$X_{d(eq)} = \frac{\Delta e}{\Delta i}$$

The equivalent reactance as determined by this method could be used in calculations as well as forming a basis for the comparison of various machines.

In the near future, the equivalent reactance probably will be used as a basis of comparison for various machines under steady state operating conditions just as the transient reactance is used today for transient conditions. If this be the case a standardized method of measuring this reactance will have to be adopted. In analyzing the saturation problem, the leakage reactance is here taken as the one that is not affected by saturation and the rest of the synchronous reactance is taken as the saturated part. The Potier reactance certainly should not be taken as the unaffected part because it actually does vary over a wide range (200 or 300 per cent) with saturation. At present there is not a standardized definition of leakage reactance. Hence, in order to cope with this saturation problem correctly and to form a sound basis for future contributions to the art along this line, I would suggest that the standardizing committee of the A.I.E.E. look into, or at least consider, the possibility of arriving at a definition of leakage reactance for general use and thus among other advantages place the comparison of machines on a rational basis.

H. B. Dwight: The paper by Crary, Shildneck, and March shows that, for steady state loads at voltages involving saturation of synchronous machines, values of synchronous reactance, if used, should be considerably smaller than the "unsaturated" value obtained from a test by short circuit at the terminals. It is gratifying that their conclusion, while different in method, is similar to that described in my paper which they quote as Ref. 4. An advantage of their method is that the effects of pole leakage flux and load power factor on synchronous reactance are taken into account. Their method has been compared with tests, as stated in their paper. A very satisfying test for the over-all accuracy of this method of calculation is to show maximum power in kilowatts, by test and by calculation, and it would be of interest if the authors would give such an example. The details of such a sample calculation would also be of assistance to those who wish to make practical calculations according to this method. It is to be noted that a special value of voltage, E_{eq}, is found and used with the special synchronous reactance, in calculating power, and so the values of synchronous reactance in this and other papers are not directly comparable.

Another practical problem is that of natural frequency of rotatory oscillation of a synchronous machine. Some careful measurements of this have been made at the Massachusetts Institute of Technology, and the writer hopes to present them in the near future, together with corresponding calculations by adjusted synchronous reactance.

To the list of references that have described the need of special values of synchronous reactance, there might be added the paper by E. B. Shand (A.I.E.E. Trans., 1924, p. 59; discussion p. 96) in which steady-state maximum power is correctly calculated by families of curves. The statement is made in Mr. Shand's discussion on p. 97 that the method of synchronous impedance "will prove inaccurate unless great care is used in the choice of synchronous impedance to represent a given machine."

E. H. Freiburghouse: Crary, Shildneck, and March have developed an ingenious graphical and mathematical method for determining, more accurately than heretofore the steady state power limit; also the

synchronizing power coefficient at any operating load on a synchronous machine.

They have accomplished this by developing from differential equations and point coefficients approximate, and also accurate, equations for obtaining equivalent synchronous reactances which are employed in the usual manner, instead of the unsaturated synchronous reactance. It should not be overlooked that with saturation there is a different equivalent synchronous reactance for every different load condition also an equivalent excitation voltage e_{eq} and displacement angle δ_{eq}.

It seems from the data indicated in the authors' Figs. 5, 6, and 7 that machines having very low short circuit ratios and high values of leakage reactance and excitation voltage e_d should have relatively greater values of k, more saturation, larger ratios a/b, and therefore lower ratios of equivalent reactance x_{eq} to unsaturated reactance x_d. This indicates that the steady state synchronizing power coefficient of low short circuit ratio machines may not be as poor relatively as the short circuit ratio indicates.

Comparing curves in the authors' Figs. 9 and 12 for the synchronizing power coefficients of cylindrical rotor and salient pole generators the conclusion may be reached that the influence of saturation is of greater magnitude in the case of cylindrical rotor machines, however the salient pole generator for which these curves were calculated may not necessarily be representative of salient pole machines.

In applying the equations given in the paper care should be taken to ascertain whether the coefficients k and a/b, given in the authors' Figs. 5, 6, and 7, are applicable to the machine in question.

In the authors' Appendix E, eq 6-E was obtained by substituting $k = 1$, $a/b = 0$, and $x_d = x_{eq}$ in the differential equation 2-E. The general equation (6-E) for x_{eq} also could have been obtained by differentiating equation

$$e_{eq} = \sqrt{e_t^2 + i^2 x^2_{eq} - 2e_t i x_{eq} \cos(90 + \theta)}$$

obtaining

$$\frac{de_{eq}}{di} = \left[e^2_t + i^2 x^2_{eq} + e_t i x_{eq} \sin\theta\right]^{-1/2} \times \left[e_t \frac{de_t}{di} + i x^2_{eq} + \left(e_t + i\frac{de_t}{di}\right) x_{eq} \sin\theta\right]$$

Now if excitation e_{eq} and θ are assumed to be constant it follows that

$$e_t \frac{de_t}{di} + i x^2_{eq} + e_t x_{eq} \sin\theta + i x_{eq} \sin\theta \frac{de_t}{di} = 0$$

Hence

$$x_{eq} = -\left(\frac{de_t}{di} + \frac{e_t}{i}\right)\frac{\sin\theta}{2} + \sqrt{\left(\frac{e_t}{i} + \frac{de_t}{di}\right)^2 \frac{\sin\theta^2}{2} - \frac{e_t}{i}\frac{de_t}{di}}$$

and when $\theta = 0$ and power factor equals unity

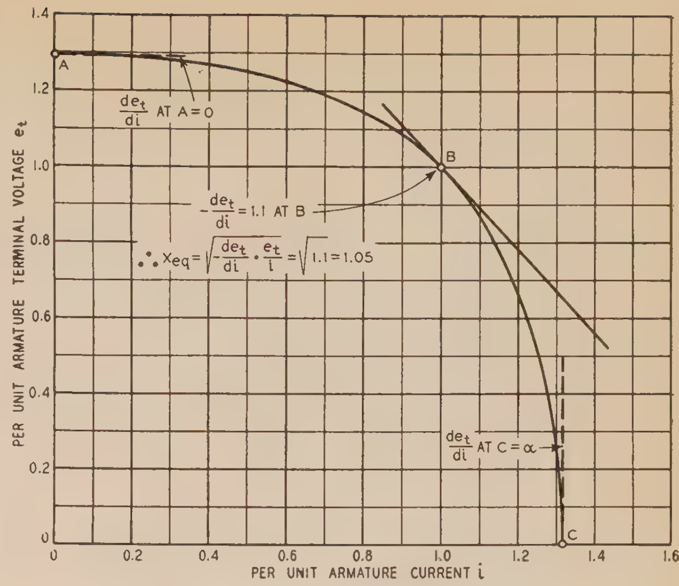
$$x_{eq} = \sqrt{-\frac{e_t}{i}\frac{de_t}{di}}$$

or when power factor is zero $\theta = 90$ deg

$$x_{eq} = -\frac{de_t}{di}$$

Fig. 2. For generator No. 1

Cylindrical rotor characteristic for field current corresponding to rated armature terminal voltage and current at unity power factor. Points A, B, and C determined by test



Others of the authors' equations (15, 16, 17) show that the equivalent synchronous reactance of cylindrical rotor type machines when operated at any particular field excitation, terminal voltage, and constant power factor can be obtained quickly by means of the voltampere characteristic. Or conversely, these relations can be used in determining the shape of the voltampere characteristic.

For zero power factor, the equivalent synchronous reactance x_{eq} is simply the negative per unit slope of the voltampere curve at the particular operating voltage. The zero power factor voltampere curve must approach and then coincide with a straight line having a slope numerically equal to the per unit unsaturated synchronous reactance, x_d, as the terminal voltage approaches zero. That is, the equivalent reactance at low voltage must be the unsaturated synchronous reactance, x_d, as no appreciable saturation exists in the machine at these low voltages. Since the 3 points A, B, and C of Fig. 4 of this discussion may be determined from test data, the voltampere curve at zero power factor may be drawn in quite accurately by making the curve coincide at B and C with the straight lines through B and C, the slope of the straight line through point B being determined by the authors' eq 4-E and that through C having a slope equal to the unsaturated synchronous reactance.

Also at unity power factor, for a given voltage and a particular excitation, the slope $-\frac{de_t}{di}$ of the voltampere curve may be estimated by means of the authors' eq 3-E. Or, if the slope of the voltampere curve is determined from test, the equivalent synchronous reactance at the given voltage may be obtained by means of the equation $\sqrt{-\frac{de_t}{di} \times \frac{e_t}{i}}$. The curves in Figs. 2, 3, and 4 of this discussion were made to pass through points A, B, and C which were determined by tests and drawn tangent to lines having slopes conforming to the authors' eq 3-E. At unity power factor the voltampere curve has an infinite slope at zero voltage and a zero slope at zero current. This result is obtained directly from the authors' eq 5-E for unity power factor, $\theta = 0$.

In a similar manner, voltampere curves may be readily drawn for any power factor and excitation by making use of 3 test points, by estimating the slope at the given voltage by means of the authors' eq 2-E and by determining the slope at zero voltage by means of the authors' eq 5-E (which, for $e_t = 0$ and $x_{eq} = x_d$, yields $\frac{de_t}{di} = -\frac{x_d}{\sin\theta}$). These relationships should prove to be useful guides in determining the voltampere characteristics, or if the voltampere characteristic is known, the equivalent synchronous reactance for the conditions corresponding to the voltampere characteristic may be determined accurately (authors' eq 6-E).

Table I—Data for Determination of Equivalent Synchronous Reactance

Generator	No. 1	No. 2	No. 3
e_t (test)	1.0	1.0	1.0
i (test)	1.0	1.0	0.98
Power factor	1.0	1.0	0
θ	0	0	90°
e_d (test)	1.705	1.315	2.31
e_t when $i = 0$ (test)	1.293	1.105	1.385
i when $e_t = 0$ (test)	1.315	1.78	2.04
x_d (test)	1.293	0.742	1.135
x_l (calc.)	0.133	0.106	0.17
e_l (calc.)	1.009	1.006	1.167
k (calc.)	1.058	1.065	1.20
e_d (calc.)	1.675	1.305	2.34
δ (calc.)	50.7	34.2	0
a/b (calc.)	0.327	0.313	1.115
$-\frac{de_t}{di}$(calc. for $e_t = 1.0$)*	1.1	0.418	0.533
x_{eq} (calc. equations 16 and 17)	1.05	0.646	0.533
e_{eq}(calc.)	1.455	1.193	1.52
δ_{eq} (calc.)	46.6	33.0	0
P (equation 13)	1.0	1.0	0
$dP/d\delta_{eq}$ (equation 14)	0.954	1.55	2.85
x_{eq}/x_d	0.812	0.87	0.47
δ_{eq}/δ	0.917	0.965	.....

*Calculated by authors' eq 3-E for unity power factor and authors' eq 4-E for zero power factor.

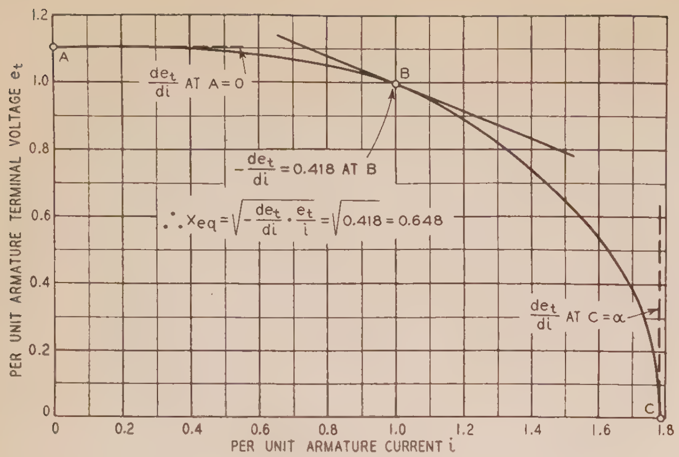


Fig. 3. For generator No. 2
Cylindrical type rotor characteristic for field current corresponding to rated current and voltage at unity power factor. Points A, B, and C determined by test

Data are given in Table I of this discussion by means of which the equivalent synchronous reactances were obtained for the 3 generators having voltampere curves presented in Figs. 2, 3, and 4. Data also are given in the table showing relative values of excitation, displacement angle δ, and synchronous reactance for the saturated and equivalent unsaturated cylindrical type rotor generators of both high and low short circuit ratios.

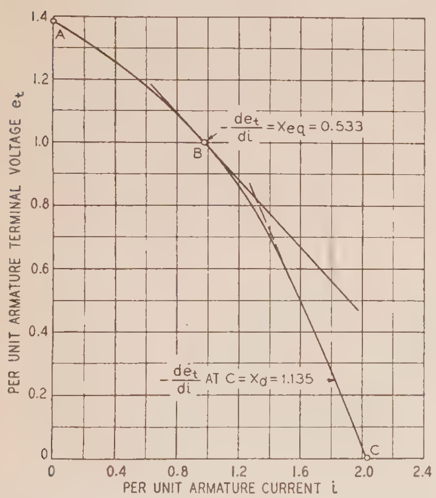


Fig. 4. For generator No. 4
Armature terminal voltage and current for field current corresponding to 0.98 rated current at rated voltage and zero power factor. Cylindrical type rotor overexcited. Points A, B, and C determined by test

Sterling Beckwith: The authors' analysis of the effect of saturation on synchronous reactance is most interesting. I have gone over it in considerable detail, but its completeness and exactness leave little to add.

The problem solved is of considerable importance in the design of the Metropolitan Water District's line for transmitting power from Boulder Dam to the pumping plants along the Colorado River Aqueduct. This is for the reason that the simplicity of the system and the relative unimportance of transient stability will allow normal operation to be much closer to the steady state stability limit than in most other comparable systems. Since the reactance that determines the steady state limit will be largely synchronous reactance, the effect of saturation will be important. The District consequently made its own determination of the effect of saturation, and although the method used was more approximate than that used by Crary, Shildneck, and March, it gave results which were easier to use, and which were found to be sufficiently exact for the intended application. The original derivation will not be given here, but the same results will be obtained from the equations of the authors' Appendix C, as the simplification of the results may be of some interest.

If it be assumed that no saturation exists in the quadrature axis, i. e., that the vector $(K_1 - 1)e_l$ in the authors' Fig. 3 of the paper is parallel to the direct axis, e_d, then the effect of saturation on synchronous reactance does not depend on conditions external to the machine itself.

To illustrate, take equation (C-9) and assume that the armature saturation is zero and that the direct axis armature saturation is included in K_1. Then

$$X_{d(eq)} = X_l + (X_d - X_l)\,\frac{1}{K_1\left(1 + \dfrac{a_1}{b_1}\right)}$$

which is independent of external conditions. Further simplification of this equation gives:

$$= X_l + (X_d - X_l)\,\frac{b_1}{K_1(b_1 + a_1)}$$

$$= X_l \;\; (X_d - X_l)\,\frac{TR}{K_1(TR + RO)}$$

See authors' Fig. 2

$$= X_l + (X_d - X_l)\,\frac{TR/TP}{\dfrac{TP}{TL}(TO)/TP}$$

$$\text{Since } K_1 = \frac{TP}{TL} \text{ and } (TR + RO) = TO$$

$$= X_l + (X_d - X_l)\,\frac{\text{slope of sat. curve}}{\text{slope of air gap line}}$$

$$\text{since } \frac{TR}{TP} = \text{slope of sat. curve}$$

$$\text{and } \frac{TO}{TL} = \text{slope of air gap line}$$

The saturation curve to be used is that including only direct axis saturation. Crary, Shildneck, and March plot this as e_l against Ke_l, but as only the ratio of 2 slopes is need, it can be plotted in any terms desired. I have found it more convenient to use e_{ld} as the ordinate and ampere turns as the abscissa, as the curve then becomes identically the no load saturation curve when $e_l = e_d$. If e_l does not equal e_d, the curve is altered only because the field form of the machine is altered by the demagnetizing ampere turns. I have found that the correction for this distortion is small, and that it is almost as accurate, and more convenient to correct the voltage at which the slope of the saturation curve is taken than it is to change the saturation curve, as this allows the no load saturation curve to be used for all operating conditions.

To show for an average saturation curve, how the voltage e_{ld} varies with operating conditions, the curve of Fig. 5 of this discussion was drawn. To illustrate: If the machine operates with a field current of 3, and with a load that gives a terminal voltage of 0.92 and a power factor of 0.80, then the saturation is the same as that at the no load voltage 1.2 (obtained by following the

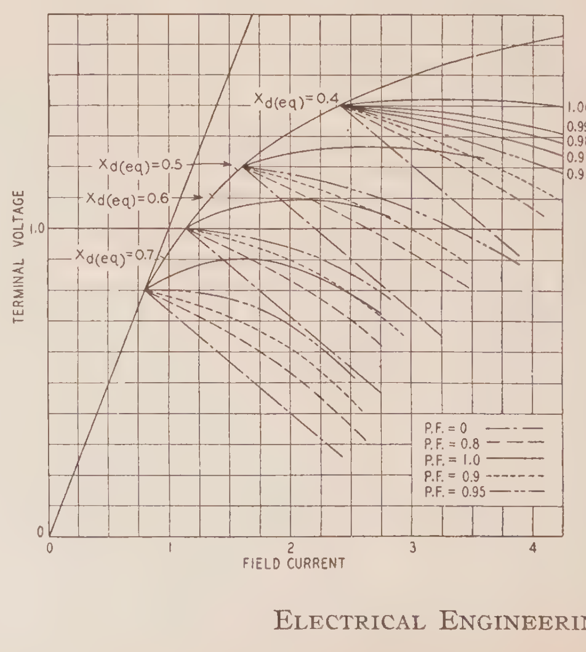


Fig. 5. Lines of constant direct-axis components of internal voltages—from vector diagrams for a wound-rotor machine with $X_d = 4X_l$

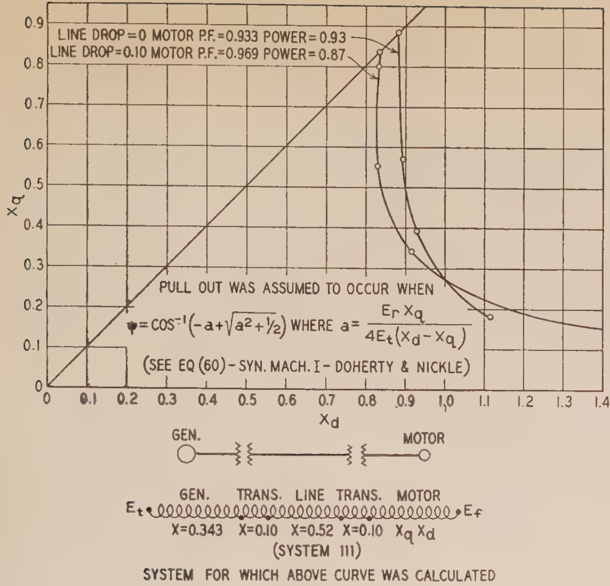


Fig. 6. Maximum values of x_q and x_d of motors with power transmitted over the system shown in the sketch—line capacitance = 0; system losses = 0

line for 0.8 power factor back to the no load saturation curve) and the saturated reactance is equal to the leakage reactance plus the demagnetizing reactance times the ratio of the slope of the no load saturation curve at this voltage of 1.2 to the slope of the air gap line. A correction for the difference between the flux form at no load and at the operating point could have been made if desired, by correcting the voltage 1.2 by a suitable amount.

To show that the effect of the above assumption of no quadrature axis saturation does not materially affect the steady state stability calculations, the curve of Fig. 6 of this discussion was drawn. This curve was obtained using the equivalent system and power limit equations shown on it, and shows that power limit is dependent almost entirely on X_d for X_q greater than half of X_d.

One thing I would like to ask the authors is whether the salient pole generator they chose for numerical calculations was a representative one. About 75 per cent of the saturation under no load conditions (i. e., $e_l = e_{ld} = e_t$) appears to exist in the armature, whereas it was my opinion that 25 per cent was a more usual figure at normal voltage, and that this figure should decrease due to field leakage as the voltage increased, instead of increasing as shown.

R. D. Evans: The paper by Crary, Shildneck, and March discusses methods for determining the effects of saturation in modifying the values of machine reactances used for various purposes, particularly for steady state stability calculations. From a technical viewpoint, it is desirable to provide a more rational basis than has heretofore been available in evaluating effects of saturation on the machine reactances and the paper is valuable from this standpoint.

Certain parts of the paper, particularly Figs. 8 and 11 may give the impression that the effects of saturation have heretofore been neglected in determining machine reactance to be used for stability calculation. From this standpoint, these figures would have been more useful if they had compared the results of the proposed method with the empirical methods in use. One of these methods, which has been used in stability work for ten years, is based on the determination of the excitation of the machines for the load conditions assumed by any conventional method. Then for the value of excitation so determined the machine reactance is taken as corresponding to the difference in voltage between the no load and the zero per cent power factor saturation curve. In general, this method has given very satisfactory results for ordinary conditions of operation, where steady state stability would be of interest, which conditions include operation near unity power factor on the generator and with considerable impedance in the external system. Figs. 8 and 11 relate the appropriate value of machine reactance to the external impedance instead of the excitation of the machine field. Therefore, the figures tend to conceal the effect of variation in field current on the appropriate value of machine reactance.

From a practical standpoint it seems desirable to express the opinion that these equivalent reactances for computing steady state stability limits of generators supplying power systems will not supplant the values in common use, namely, short circuit ratio as a general index for measuring the sizes of machines and transient reactance for determining the transient stability characteristics. The conventional methods of figuring steady state stability appear to be sufficiently accurate for the ordinary cases. Where steady state limits may become of importance voltage regulators will be used and for such cases the stability limits will not be determined by the reactances described in the paper. Furthermore, steady state stability is rarely the actual stability limit of a system since this is normally determined by transient conditions arising principally from system faults.

The paper is viewed as an important contribution in rationalizing effects of saturation but is reassuring that present methods of calculations will not, for the present at least, be greatly effected.

L. A. Kilgore: The authors present in this paper a new method of calculating an equivalent synchronous reactance for use in steady state stability calculations. The method proposed is less empirical than the conventional method referred to in the (accompanying) discussion by R. D. Evans, but far more complicated. Even the approximate method suggested for salient pole machines (eq 10) involves separate curves for stator and rotor saturation and armature and field leakage constants. These factors cannot be tested for separately and can only be calculated by the designer of the machines, and the more accurate formulas (eqs D-7 and D-8) are very complicated indeed. These things make the method of little value as a practical method of calculation.

The chief value of this paper is apparently in its contribution to the theoretical analysis of the effects of saturation, for an accurate method of dealing with saturation is valuable as a means of checking the simpler empirical methods. The authors have carried their analysis out quite thoroughly, but they still neglect certain factors which appreciably affect the saturation.

The authors assume that the stator saturation is a function only of the vector sum of the terminal voltage and leakage reactance drop. However, consideration of the actual flux distribution in the air gap shows that under load the maximum gap density increases more than the fundamental density, hence the tooth saturation may be much higher than calculated on this assumption. The effect of the pole tip

Table II—Comparison of Methods on Salient Pole Machines

% Kva load	173	125	100	142	178
% Power factor	90	96.8	98	100	100
% Direct synch. react. (X_d)	89	83	85	102	83
% Quad. synch. react. (X_q)	65	58	62	75	58
% Sat. at no load in % of air gap	19	15	19	23	15
% Leakage reactance (X)	8	6	8	8	6
% Potier's reactance (X_p)	17	13.5	16	17.5	13.5
Calculated Field Current in % of Test Value					
Using authors' assumptions	99.0	95.5	98.5	98	96.0
Using direct axis projection of E_p	98.0	95	98	97.5	96.5
From no load and 0.0.p.f. sat. curves	102	102	100.5	101.5	103
Using Potier's react. voltage (E_p)	102.5	102	101.5	103	104.5
No saturation considered	83.5	86	86	87	88
Calculated Equivalent Reactance X_{deq}					
Author's approximate method	37	50	46	58	50
Potier's reactance method (E_{pd})	40	54	46.5	60	54
From no load and 0.0.p.f. sat. curves	37.5	46	40	47	46

saturation is not included, but consideration of the actual densities in pole tip under other than zero power factor load shows appreciable increase in saturation for many machines.

These effects show up in the comparison with tested field currents shown in Table II of this discussion. Field current calculations based on the authors' assumption checked quite well at zero power factor and fairly well at 0.8 p.f., but at 0.9 to 1.0, the calculated currents as shown by the table are consistently low, the average being 97.5 per cent of the tested field current. The comparison was also carried out for the other methods, and it is interesting to note that the standard A.I.E.E. method of using tested no load and zero power factor curves is consistently high, averaging 1.8 per cent high for these machines.

A third method of calculating the equivalent reactance has been suggested (in an accompanying discussion) by Sterling Beckwith. This method assumes that the saturation is a function of the direct axis projection of the voltage behind Potier's reactance (E_{pd}), and on this basis, it can be demonstrated that the equivalent reactance is

$$X_{deq} = X_p + \frac{(X_d - X_p)}{S_{pd}}$$

where S_{pd} is the ratio of the slope of the no load saturation curve at the voltage E_{pd} to the slope of the air gap line.

This method, while not based on quite as accurate assumptions as those used by the authors, is far more usable. It is nearly as simple as the conventional method referred to by Evans and has the advantage in that it is less empirical and gives a reactance value which is higher than the actual value rather than too low, and when used in stability calculations, gives results which are on the safe side.

Protecting Machines From Line Surges

Discussion of a paper by J. F. Calvert published in the January 1934 issue, p. 139–46, and presented for oral discussion at the electrical machinery session of the winter convention, New York, N. Y., Jan. 25, 1934.

Edward Beck: J. F. Calvert has presented data that will make practical a close coordination of rotating machines and protective devices because in his paper appears a method of calculating the permissible rate of rise of surge voltage at the machine terminals. The machine designer should now be able to furnish the protective engineer with specifications for the permissible crest and rate of rise of voltage at the machine, and the protective scheme can be designed accordingly. In general, the protective schemes that already have been proposed, have sufficient margin to protect the usual machines; but, in such cases as large high voltage machines for instance, exact data on the permissible rate of rise of voltage no doubt will not only give greater security, but will permit use of the most economical protective equipment.

Particular attention should be drawn to Appendix II of the paper in which the effect of reflections between a capacitor at the machine and an arrester on the line at some distance is discussed. In any such scheme, as proposed in references 8 and 13 of the paper's bibliography, these reflections enter into the picture because they very strongly influence the rate of rise across the capacitor.

What happens is that at first the voltage that travels toward the capacitor is the voltage that passes the line arrester, with which is associated a certain current depending on the surge impedance of the line between them. When this voltage reaches the capacitor, the capacitor reduces the voltage, sending back toward the arrester a reflected wave of opposite polarity. When this wave reaches the arrester it tries to reduce the voltage at the arrester, but usually the original lightning surge on the line will have sufficient energy and duration to keep the voltage up to the arrester terminal voltage. Consequently the line from the arrester to the capacitor must draw more current than it did before; in effect current is transferred from the arrester to the line and into the capacitor, which consequently must charge at a higher rate than it did before. These changes in the charging rate of the capacitor will occur at intervals of the time it takes the surge to travel from the capacitor to the arrester and back again. If the distance between them is 2,000 ft the time interval is 4 μ sec. It is likely that the lightning disturbance causing the surge will be of greater duration than this. Therefore, it is likely that reflections between the arrester and the capacitor will occur. These will, for the first few reflections, increase the charging rate of the capacitor, and the steepness of the wave front applied to the machine.

In the paper presented a year ago by Rudge, Wieseman, and Lewis ("Protection of Rotating A-C Machines Against Traveling Wave Voltages Due to Lightning," A.I.E.E. TRANS., v. 52, June 1933, p. 434) there are curves showing the calculated rate of rise of voltage across the capacitor in the scheme also shown by Calvert's Fig. 16. These are based upon the application of arrester voltage only to the capacitor, with no reflection between the capacitor and the outer arrester. A closer approach to the actual conditions would show steps of increasing rate of rise at 4 and 8 μ sec, and further modifications of positive or negative influence thereafter.

In other words, the charging rate of the capacitor is determined not only by the arrester voltage and the surge impedance of the line between them, but by the distance between them as well, as was pointed out in the article by Calvert, Monteith, and Beck, published in the *Electric Journal* of March 1933. They are caused by an increase in current into the capacitor, or they may be looked at as caused by successive decreases in the resultant surge impedance of the line as the reflection takes place. They are calculated by the methods outlined by Calvert in his paper. These reflections between the line arrester and the capacitor are of greater importance than reflection from the machine neutral since the machine neutral is removed from the capacitor in microseconds several times the interval between the capacitor and the arrester.

A. C. Monteith: The protection of rotating machines directly connected to exposed lines has been developed to the point that a scheme now can be selected with a knowledge of its limitations. J. F. Calvert's latest contribution presents a method of analysis which will simplify the application of protective devices to rotating machines.

It is of interest to note that all schemes utilize lightning arresters in various locations. In the case of the delta connected machine and star-connected free-neutral machine arresters have been suggested at the mid-point of the delta to ground and at the neutral to ground respectively to prevent reflections, thereby reducing the amount of capacity necessary at the terminals of the machine. If the machine acted as a transmission line, even with the arrester, a voltage of short duration in excess of the arrester voltage should appear. It is of interest to note that Figs. 3 and 5 of Calvert's paper collaborates the results of other tests showing that in the case of rotating machinery this voltage does not appear. This fact allows a more economical protective scheme than if arresters could not be used at these points and further eliminates the necessity of making assumptions as to the length of the incoming surge.

An Experimental Ignitron Rectifier

Discussion of a paper by L. R. Ludwig, F. A. Maxfield, and A. H. Toepfer published in the January 1934 issue, p. 75–8, and presented for oral discussion at the electrical machinery session of the winter convention, New York, N. Y., Jan. 25, 1934.

C. C. Herskind: A comparison between a new piece of apparatus and an old one of similar size or rating always is of interest. It helps us to distinguish those factors that are new and to determine what has been gained. Several years ago an experimental polyphase rectifier of about the same size as the polyphase ignitron described in the paper was tested in Schenectady. This rectifier had an inside diameter of approximately 16 in. and was 16 in. high. I believe the polyphase ignitron shown in the author's Fig. 2 is about 13 in. in inside diameter and 3 in. high. The rectifier that was tested at Schenectady was of conventional design and had 3 anodes. It carried loads of from 300 to 350 amp at 750 volts. It also operated at 1,500 and 3,000 volts.

From these data the 2 rectifiers seem to have approximately the same current rating, although the conventional rectifier was operated at a higher voltage than the ignitron. An important difference between the 2 rectifiers is found in a comparison of the losses. The data presented in this paper indicate that the arc drop of the ignitron rectifier is considerably lower than that measured in the conventional rectifier.

If operating experience in actual service proves the reliability of the igniter and the other new features in the ignitron rectifier, this reduction in arc drop will be an important step forward in rectifier development.

I would like to ask the authors of this paper whether they believe that rectifiers using the igniter principle can be built for higher voltages, higher current loading, and higher vapor pressures.

One of the ignitrons described in the paper shows a cooling coil in the cathode pool. Have tests indicated that any appreciable reduction in arc drop might be obtained by this means?

Selby Haar: It appears from the authors' Fig. 2, that the anodes are mounted on relatively long rods secured at the upper ends. Has observation showed any tendency for these rods to vibrate transversely, particularly with pulsating currents? This vibration if of large magnitude would cause a short circuit.

An Economic Study of Suburban Distribution

A. H. Sweetnam and C. A. Corney, January 1934 issue, p. 97–102.

Radial Versus Primary Network Distribution

H. E. Wulfing, January 1934 issue, p. 38–42.

Fundamentals of Design of Electric Energy Delivery Systems

J. Allen Johnson and R. T. Henry, December 1933 issue, p. 831–8.

Joint Use of Poles With 6,900-Volt Lines

W. R. Bullard and D. H. Keyes, December 1933 issue, p. 890–8.

Discussion of a group of papers presented for oral discussion at the session on power distribution of the winter convention, New York, N. Y., Jan. 25, 1934.

C. T. Sinclair: The committee on power transmission and distribution, through its subcommittee on distribution, has been arranging for the presentation of a number of papers dealing with the economics of distribution systems. The papers presented at this session are the first of the series. It is expected that other papers now in various stages of preparation will be made available for later meetings.

There seems to be an opinion prevailing in certain quarters that the overhead distribution system merely is an assemblage of poles, wire, and fixtures, and, on this basis, certain cost estimates have been disseminated which easily may lead to erroneous conclusions. Also there seems to be an opinion prevailing that the distribution system is the much abused stepchild who has been all but ignored in the family circle.

The papers, together with others that may follow, were arranged to present to the membership ample evidence that neither of these conclusions necessarily is true. Even a casual reading of the papers will result in the conclusion that the type of system is of fundamental importance, and that the authors and their associates have given much thought and intensive study to the problem. It is believed that a study of these papers will result in the conclusion that the distribution system is something more than poles, wires, and fixtures.

While it is true that the engineering thought given to the distribution system has not in all cases been as extensive as perhaps warranted, we know that analyses such as are described in these papers have been and are being made all over the country.

We observe that the authors in certain instances have not come to the same conclusion as to the type of system best suited to their local situation. These differences are to be expected. Local conditions and limitations play an important part in the economic choice of a type of distribution system. Some of the factors are:

1. The Existing System. The type of system existing has a definite bearing on the method used for expanding the system. In most cases we must live with the existing system and expand it. It is the exceptional case where we can start with a clean slate and build from the ground up.
2. Local Restrictions and Ordinances. Almost every locality has some form of local restriction which affects the design principles and costs. Certain streets are underground by ordinance, overhead conductors may not be run across streets, transformers may not be located on certain streets, etc.
3. Topographic Conditions. Some localities are favored with straight and uniform streets and a level area. Others have crooked streets, intersecting at angles, and not continuous, with ravines and hills which result in difficulties in construction and may render one type of system more economical than another.
4. Local Conditions. There are many local conditions, usually of minor importance, which when taken collectively often affect the principles of design. For example, many cities have alleys which effectively can be used for pole lines. In the case where such an alley is adjacent to and parallels a street underground by ordinance, an appreciable saving in cost will result as overhead lines may be run in the alleys. Another local factor usually of minor importance but which may be of major importance is that of large city estates, scattered throughout a normal residential area. Circuitous pole routes result in some cases; larger copper is necessary.

These factors must necessarily result in certain differences in the types of systems. The paper by Messrs. Sweetnam and Corney arrives at one conclusion, and the paper by Messrs. Johnson and Henry arrives at another. Mr. Wulfing has still another solution. Messrs. Bullard and Keyes have presented a different phase of the distribution problem—the utilization of a higher voltage for distribution purposes.

While the solution of Messrs. Sweetnam and Corney differs materially from that of Messrs. Johnson and Henry, they may not be as divergent as might appear. There seems to be one important factor which is common to both—the use of relatively small transformation units. Because of space limitations, it is not possible for the authors to describe but little more than the high spots and conclusions of their study. The discussion will undoubtedly bring forth certain questions of engineering interest. We do not believe that it is the thought of any of the authors that their particular conclusion is the universal answer, and that their solution and only their solution applies to all areas. We may differ with any or all of the authors' opinions, but we must conclude that they have thoroughly studied their own problem and have come to a conclusion that will result in an efficient system of electric distribution for their community.

D. K. Blake: "Circumstances alter cases" is a maxim that certainly is true in the realm of distribution economics, as evidenced by the 4 papers presented at the winter convention session devoted to that subject. Several generalizations can be made from these papers and from more than 20 different studies I have made or reviewed, covering as many actual different circumstances.

1. No one system of distribution is so economical or universal as to exclude all the others from consideration.
2. Circumstances do occur that have a pronounced effect in favor of one system and against others.
3. High voltage radial systems, low voltage radial systems, overhead secondary networks, aerial cable systems, and primary network systems have places of economic superiority in the industry.
4. The existing system usually has the most influence as a circumstance favorable to one system and unfavorable to the others.
5. All factors and circumstances combine to present a complicated problem that requires intensive study and much labor.
6. The very complexity of the problem makes it quite easy for anyone to overlook the particular circumstances that make one system a better solution than others.
7. Studies based on uniform ideal conditions can do no more than show the relative importance of the factors influencing the total cost but they are valuable for that purpose.
8. Studies based on actual conditions are not conclusive until the circumstances favorable to one system and unfavorable to others have been carefully analyzed and shown to be real and not artificial, resulting in misapplication of the systems appearing to be unfavorable.
9. All new schemes make a greater use of transmission voltage and provide for load growth in smaller increments with varying degrees.

The term "primary network system" was coined to convey the idea of a primary distribution system having the same fundamental technical features and fundamental economic principles as the well known secondary network system. Now, in the secondary network system, circumstances do occur in practice where it is more economical to place two or more transformers (supplied from as many high voltage feeders) in the same vault connected together on the secondary side to a common bus. This bus may be tied into a street network or any number of such vault installations might exist without any secondary interconnection between the vaults whatsoever. No matter which it

is, all cases are commonly referred to in literature and in conversation as a secondary network system for the reason that the same equipment, features, and principles are employed that are inherent in a network supplying a uniformly distributed load. Of course, it is certainly true that those cases having no interconnected secondaries between vaults are radial secondary substations. Hence, we have, in loose language, networks that are radial systems and radial systems that are networks.

In the early years of the secondary network system, it was necessary to do a considerable amount of educational work to show that the system was flexible, permitting the same equipment, features and principles to be used in those cases where the circumstances made it economical to use the radial bus instead of the network grid.

Now, it is also true of the primary system that circumstances do occur where the cost of primary radial feeders is low, because of short distance or overhead construction that will make it more economical to feed from one location instead of several. The very first installation of so-called primary network equipment in South Boston was just such a case, where one unit with 2 transformers and 3 short 2.3-kv feeders was more economical. In Brookline and Pittsfield, a 4-unit grid was more economical. In Malden, Massachusetts, 2 units; and in Altoona, Pa., 1 unit, are operating as simple 1 transformer and 4 feeder radial substations, ready to be used in a network grid when the load develops. Also, the Sweetnam-Corney paper shows that the radial connection in Fig. 5 of that paper is more economical for the initial installation than a 3- or 4-unit network grid.

The Johnson-Henry paper, likewise, shows that there are circumstances in Buffalo that make it of decided economy to place 3 of their standard units at one location with 9 short radial feeders instead of forming a network with 1,500-kva units. Reference to Figs. 2 and 3 of that paper will show clearly that these substations are the exact equivalent of 3 2500-kva primary network units and, therefore, employ the same equipment, technical features, and economic principles as the primary network systems in Pittsburgh, Boston, Pittsfield, Altoona, and Malden. Anyone could call the Buffalo radial system a primary network system with the same reasonableness that they would the secondary radial system in the Chrysler Building in New York a secondary network system. It is obvious that equipment could be standardized by manufacturers to be used either way, with substantial savings to the industry.

Mr. Wulfing's paper presents in a commendable manner an analysis that shows the primary network, in the form of a grid, costs somewhat more than their standard automatic radial substation system. Everything favorable to the primary network system seems to have been taken into consideration, although I do feel that 6 network units instead of 10 would be ample in view of the overload capacity of the transformer for emergency operation. If advantage were taken of this, the network would show up favorably.

Perhaps Mr. Wulfing will present some figures, showing the saving, even though his company may not care to operate in that manner, even if an actual saving did occur in favor of the network. It would also be of benefit to the industry if he would present a comparison with three network units on one lot, connected similar to the Buffalo system. Two cases should be studied, one using two three unit substations and the other three three unit substations. Another circumstance of importance in the Chicago case is that a large number of underground network ties are used which surely make it almost impossible to justify a network arrangement, unless the same underground ties would have to be there in the radial system as well.

Now, I would like to present a comparison between the network system as a grid and the identical units connected as a radial system. This will permit us to see clearly just what the circumstances are that would permit us to expect the grid arrangement to be the most economical. Space, however, precludes this, so it will have to be reserved for a future paper.

Such an analysis will show that there are 2 requirements in order for the network system to have a substantial economy over the equivalent radial system. First, the circumstances must be such that the network will actually save 4-kv cable and underground construction. Second, that for large areas, permitting a common network over the entire area—or, what is the same thing, a smaller area of higher density, permitting a large number of units interconnected into a common network—the network not only will save money on cable and conduit, but also will save money on substations and even transmission cable, if the distance between the area and the generating station is substantial. Any attempt to apply a network to circumstances other than these is very apt to show a greater cost for the network.

W. R. Bullard: The papers by Messrs. Johnson and Henry, H. E. Wulfing, and Sweetnam and Corney are timely and of fundamental importance in view of the attention now focused on ways and means of reducing distribution costs. It seems surprising, however, that in making cost comparisons of various types of distribution systems for application to the individual local situations, not 1 of the 3 papers includes consideration of the simplest and usually the most economical of all overhead distribution systems. Perhaps this is due to the nature of the existing systems in the cities involved and to impracticability of changing the present basic system plans in considering future development; or perhaps other local conditions rule the simpler system out.

The type of system which the writer refers to as being simple and economical is the radial system utilizing the "subtransmission" voltages (6.6, 11, and 13.2 kv) directly as the primary voltage and eliminating the distribution substation. By this the writer does not mean the more expensive types of such systems, such as those employing aerial cable for the primary circuits, but rather, the most simple and inexpensive form of open wire construction.

In the paper by Messrs. Johnson and Henry, mention is made of the higher voltage primaries in connection with high load density distribution and low voltage a-c networks, but the implication seems to be that such a system is not applicable to overhead distribution involving light load densities. The system is not mentioned at all in the other 2 papers. The writer realizes that in the case of Buffalo, the subtransmission voltage of 22 kv would be somewhat more difficult to use as a primary voltage, than those of the other 2 cities, but even a voltage of this order of magnitude is not entirely impracticable.

The direct radial high voltage system has been used for a number of years in urban, suburban, and rural situations by several operating companies with the practices of which the writer is familiar, and to those who have used the system, the economic advantages of eliminating the distribution substation are obvious. Furthermore, the difficulties of construction and operation, popularly supposed in the past to accompany the use of this system, have been found to be partly imaginary and by no means insurmountable; and service requirements have been fully met.

In the conventional low voltage primary system the distribution substation represents an appreciable portion of the over-all investment. Various expedients are being used to minimize the cost of the substation and some of these are described in these papers. All efforts in this direction are highly commendable and these papers give evidence of substantial progress. The writer feels, however, that the time is fast approaching when distribution engineers generally will no longer be satisfied with the intermediate steps of cost reduction but will take the larger step involving the complete elimination of the distribution substation, and the adoption of the subtransmission voltage as the primary voltage. Where service requirements can be met by radial circuits, the radial system will be used. But this may be combined with the *low voltage* network principle to provide exceptionally high grade service in those districts or individual locations where such service is necessary.

John S. Parsons: The writer has been very much interested in reviewing the 3 papers dealing with the economics of distribution systems for 3 actual areas, especially in view of the more theoretical general economic comparisons we have made of various types of systems employing overhead distribution circuits. When the wide difference in load densities in the 3 areas, differences in the existing distribution plant, and other conditions are taken into account it is not surprising that a different system was found economic in each case.

Apparently in all of these studies the transmission circuits are all underground cables in duct. The primary network system particularly is adapted to the use of underground main transmission runs with aerial cable taps to the network units. Usually this will result in materially decreasing the system cost as compared with all underground transmission, and in the case of the Chicago study, where the costs of the 2 systems studied were very nearly the same, might have changed the conclusions; especially if advantage is taken of air-blast on the network units to provide emergency capacity when a transmission circuit is out of service.

While the conclusions reached in the Buffalo and Somerville studies are different

there is one point of similarity which is of particular interest. That is, in both cases the distribution substations used in the systems found to be the most economical are relatively small bus regulated sections without any high voltage bus or automatic switchgear on the high side of the transformers. Based upon our own work and a number of other economic studies which I have had an opportunity to review, it is my opinion that complete analyses of overhead load areas will in a very large number of cases show that the most economic system is one employing this type of substation.

These small bus regulated substations are essentially of a unit type of construction and may be made up of from 1 to about 5 units. Each unit consists of a 3-phase transformer, usually of from 1,000 to 3,000 kva capacity, a high voltage disconnecting switch, regulating equipment, low voltage breaker, secondary bus, probably 2 to 4 distribution feeder breakers, and a bus sectionalizing breaker for tieing together the busses of adjacent units. Standardizing on a few such factory-built units I feel would be a definite step forward in the reduction of distribution system costs and warrants serious consideration. Such standardization would not prove a handicap to the flexibility so necessary in distribution system design to meet the large number of conditions encountered. The units could be used either in a radial or primary network system as the case required. And it should be possible to construct in most cases the necessary radial station by assembling a number of units of the proper capacity. The adoption of more or less standardized units somewhat along the lines I have suggested would mean that the distribution engineers of the power companies would not have to spend so much time on the details of substation design, and would thus have more time to devote to the distribution system as a whole. This should help to reduce the delivered cost of electric energy by more effectively attacking that portion of the electric power system which offers the greatest possibilities for cost reduction.

Our studies of distribution systems for overhead areas lead me to believe that there are sections of overhead load areas which can be supplied most economically by the overhead secondary network system which employs but a single voltage transformation in going from the subtransmission to the utilization voltage instead of 2 transformations as is usually the case. The adoption of such a system may make joint use of poles at relatively high voltage, that is voltages of 11 or 13 kv, extremely desirable. I have, therefore, read Messrs. Bullard and Keyes paper with much interest and would like very much to get their reactions to the possibilities of joint use in those cases where the power circuits are 13,000 volts open wire construction.

E. W. Oesterreich: In analyzing the papers it was found that it was practically impossible to reconcile the apparent discrepancies in the basic conclusions, due to the absence of supporting cost data, or to the different basis of cost determination.

We can readily understand why topographical conditions may have a great influence on the relative unit capacity costs of the various distributing systems between the substation and the point of customer utilization. However, in these papers the outstanding difference for the cost per kva of firm for capacity distribution substations. Take, for example, the substation cost estimates when compared to the equivalent network unit estimates as presented by Messrs. Johnson and Henry, and Messrs. Sweetnam and Corney. The Johnson-Henry paper shows the network unit installations as being approximately 75 per cent higher in capital investment cost than the equivalent substation installations. Messrs. Sweetnam and Corney indicate the opposite of this condition in that their network unit installation costs are approximately 42 per cent below the corresponding substation investment requirements. In another study recently completed by a company, which study involved an area of 11 square miles and a 1931 peak load demand of 32,000 kva, the analysis showed that for a distribution substation which incorporates the most recently proposed practices in economical substation design, the estimated investment cost could be lowered to a point where the total investment for the substation capacity would be approximately equal to the investment required for the network unit installations.

This wide spread in substation investment cost data would indicate not only a decided difference of opinion as to operating and engineering design requirements for a presupposed similar service requirement, but a large differential in the installation costs of the equipment.

Mr. Wulfing shows in his paper in Table IX that in the network plan the transformer units are installed as the load growth within the area under consideration and, in the surrounding station area, requires the additional capacity, while existing substation capacity is utilized to its fullest extent for the maximum period of time. In the radial feeder plan, the initial installation of the new substation appears immediately to release to the surrounding area, substation capacity of 4,000 kva in excess of that released, or rather unloaded, in the network plan. According to the table this additional released capacity amounts to a total of 14,500 kva in the first 6 years considered or, roughly, an average capacity of 2,500 kva for 6 years. To make the annual cost comparison applicable, it would appear that the annual cost of the equipment released, which is not used or useful in supplying capacity for the growth in load in the surrounding area, should be charged to the plan creating the idle investment condition. Or, if all of the surrounding station capacity made available by the radial plan is necessary to supply immediate load requirements of the surrounding area, then it would seem more equitable if the cost of the difference in the amounts of this capacity used under the 2 plans should be charged to the network plan.

Messrs. Johnson and Henry present a worthwhile contribution to the industry by clarifying the fundamentals involved in the problem of economic design of distribution systems. Unfortunately, their presentation of comparative capital costs as shown in Table II is of such a general nature that the lack of data relative to items of the subdivisions prohibits comparisons with conditions as they exist on other properties.

A system composed of small increments of capacity, installed at or near the concentrated loads when needed, and feeding into a distribution system which does not require frequent, costly circuit revision work adequately to serve the increasing demands brought about by normal growth of load and the addition of new circuits, presents economic advantages which are apparent. But local conditions, construction practices, operating, and service standards may impose such restrictions that the ideal condition cannot be obtained. The papers presented force us to recognize the engineering, economic, and operating phases of distribution as a problem which cannot effectively be subdivided into component parts such as transmission, substation, and distribution. For each of the related phases and for the composite system there is a solution which results in the lowest annual costs over a reasonable period of time. It is this solution which we must strive for regardless of precedents, and existing functional jurisdictions.

The officers and contributing authors of the power transmission and distribution committee are to be congratulated on their courage in presenting a symposium on a subject so controversial in nature as this one. The importance of the effect of differences in operating requirements and engineering design practices on distribution costs has been emphasized in the presentations. It is to be hoped for that this session will provide the necessary stimulus to distribution engineers so that the attendants at future Institute conventions will be able to derive the benefits of further thought and analysis of this problem.

Joint Use of Poles With 6,900-Volt Lines

Discussion of a paper by W. R. Bullard and D. H. Keyes published in the December 1933 issue, p. 890–8, and presented for oral discussion at the power distribution session of the winter convention, New York, N. Y., Jan. 25, 1934.

P. H. Chase: The adoption of joint use at 6,900 volts in the Staten Island area recognizes the economic advantage of this arrangement in that particular case, and also shows a highly commendable attitude of coöperation by the power and telephone interests. It is through trial in particular situations such as this that experience can be gained with which to meet the ultimate requirements of both systems occupying the same territory in the safest, most economic arrangement. The study was concerned mainly with the economics and relative safety of certain phases of power and telephone distribution. The economics of this particular situation shows a substantial saving in investment to the electric company, and therefore this was a major consideration. From the standpoint of hazard to telephone plant, the coördinative measures adopted in the power system are such as to impose practically no higher voltage than is the case with the more usual practice of joint use.

The paper brings out that a limiting feature in joint use at the higher voltages is the

development of telephone fuses which will operate satisfactorily at these voltages. Granting this, it is to be hoped that suitable fuses may be developed in the near future.

The evaluation of the hazard factor in studying higher voltage joint use is a most difficult problem. Both the effects when contacts occur, and the frequency of these contacts need to be carefully studied. The former has been well covered in this analysis, but the latter has not been particularly emphasized. The frequency of contacts probably is as large a factor in the solution adopted as the effects of the contact. Higher voltage joint use generally would involve higher insulation, greater clearances, faster relaying, etc., all of which work toward a lower frequency of contacts. It is quite possible that the reduction in frequency of contact may offset the effects due to increase in voltage magnitude, and thus make joint use at higher voltages as acceptable as with the lower voltages.

Satisfactory practical experience extending over about 12 years in Philadelphia with approximately 3,000 poles of joint use with open wire 13-kv lines, and both open wire and cabled telephone circuits without modifications to the plant of each because of such joint use, strongly substantiates the foregoing. The writer is inclined to feel that theoretical considerations to a great extent overemphasize the year-in-year-out hazard to telephone plant when the probable frequency of occurrence is omitted.

The writer understands there are several other areas in which there has been long-time experience with joint use involving voltages of the order of 13 kv.

It would seem particularly appropriate now to undertake detail study of such areas, in order to parallel and balance with operating results the existing theoretical and development investigations. As often happens in many branches of engineering and other human activities, quite possibly it may be found that certain greatly-feared hazards are of such infrequent occurrence as to be of infinitesimal operating importance, unusual conditions may be cleared up in unexpected ways or with negligible damage, and additional expenditures for some of the additional safeguards may be found unnecessary. The writer makes these statements without in any way minimizing the value and importance of thorough-going study of all the contingencies, but, however, urging the need for more data from operating experience.

Radial Versus Primary Network Distribution

Discussion of a paper by H. E. Wulfing published in the January 1934 issue, p. 38–42, and presented for oral discussion at the power distribution session of the winter convention, New York, N. Y., Jan. 25, 1934.

C. A. Corney: Table V of the paper gives approximately $510,000 as the present value of 10 years' annual costs of developing the 4-kv radial system. Table VIII gives approximately $550,000 as the present value of 10 years' annual costs of providing for load growth by means of a 4-kv network system. Thus, the 10-year present value of network costs is 8 per cent greater than for the radial system. It will be observed that the radial system calls for a total new investment over the 10-year period of approximately $842,000, of which about $500,000, or 60 per cent, is needed the first year. The network system calls for a total new investment over the 10-year period of approximately $1,060,000, of which only $360,000, or 34 per cent, is needed the first year.

In the Boston study, it was believed that due to the unknown effect of future occurrences on the outcome of present plans, assumptions would be progressively less accurate for the later years. In making any choice, therefore, between various plans, the later years should be given less weight than the earlier years. This factor is taken into consideration in the same manner as by the summation of annual costs discounted at 7 per cent per year, except that a factor of 15 per cent per year, compounded annually, is used, 7 per cent of which is for interest and 8 per cent for relative inaccuracy. If this method is applied to the Chicago study, the radial system gives approximately $383,000 as the present value of 10 years' annual costs, while the network system gives approximately $400,000 for the same value. Thus, the 10-year present value of network costs is reduced to a value only $4^1/_2$ per cent greater than for the radial system.

When differences between systems are reduced to 5 per cent, or below, they may be considered negligible and for all practical purposes the costs equal. The choice should then be made on the basis of other considerations such as character of service rendered with respect to continuity and regulation, flexibility in meeting load conditions and operating efficiency.

Concerning continuity, it should be recognized that faults in single radial feeders of large capacity such as 2,000 to 2,500 kva will interrupt more load than would be served from a single network main. Furthermore, 4-kv bus faults in network units do not interrupt any load, whereas bus faults in radial substations will interrupt several complete feeders until they can be switched to other busses or feeders.

Concerning regulation, it may be said that the network inherently provides a more uniform voltage condition throughout an area than can be maintained by separate radial feeders. The network bus voltage can readily be made to compensate for drop in mains, distribution transformers and their secondaries, as is being done in the Boston network, which has been in successful operation for 2 years.

The flexibility of a network system is evident as capacity may be added in small increments when and where it is required by loading conditions. This gives the network a distinct advantage in minimizing cumulative carrying charges and in closely following changes in area load centers.

Factory built network units are ideal subjects for standardization and quantity production and should always reflect this fact in their cost in comparison with substation equipment assembled and erected locally. Also it should be borne in mind that radial substation capacity rarely is used to the full, as pointed out in a recent article ("Pertinent Facts in Primary Distribution," by D. K. Blake, *Electrical World*, April 22, 1933, p. 508–12).

It is interesting to note that Mr. Wulfing's study shows lower energy losses by 35 per cent for the network than for the radial system.

F. M. Starr: Mr. H. E. Wulfing has given a very clear-cut summary setting forth the comparative costs and carrying charges for both a primary network and a radial distribution system to care for a load growth in a typical area over a period of 10 years. The results of his analysis show that the radial distribution system is somewhat less costly than the primary network although the difference is not large.

Although the scope of Mr. Wulfing's paper has not permitted a complete discussion of the various detail design factors of the 2 respective systems (i. e., primary network and radial system), it is, nevertheless, evident that he has made a very thorough study, and we may assume that, at least for this particular area, Mr. Wulfing's conclusions undoubtedly are correct.

However, I should like to point out that the conditions requiring the particular network development as described in this paper cannot be considered typical of conditions existing in the average load area of this type, and the conclusions arrived at here cannot be interpreted as having general significance.

Figure 1 shows the predicted load growth over a period of 10 years in the area under consideration. In addition, the growth in firm capacities of the proposed network and radial systems are shown, the dotted line referring to the network and the solid line referring to the radial system.

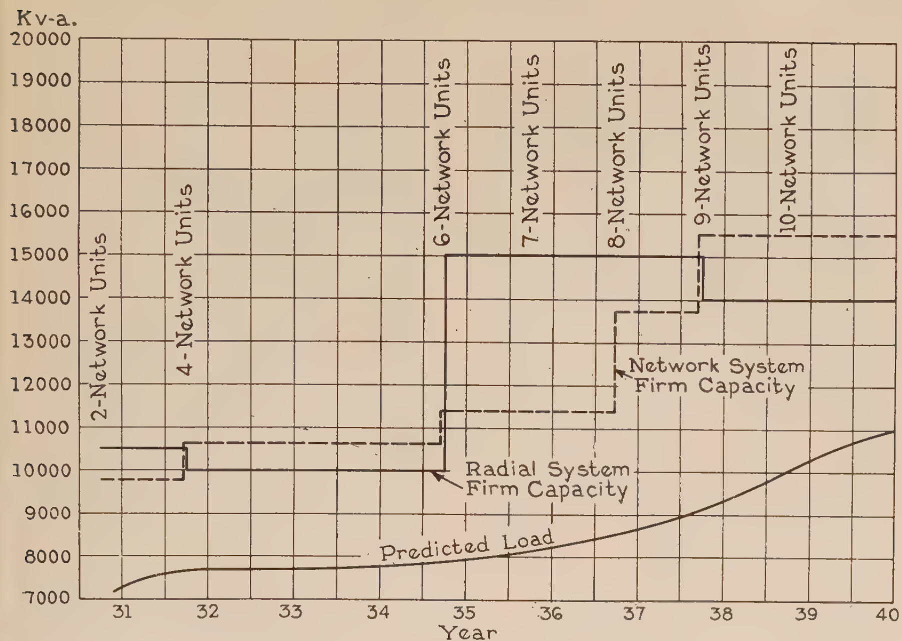
The firm capacity of the radial system is determined by assuming 1 transformer bank out of service and a permissible overload of 50 per cent on the remaining bank or banks. To this capacity is added the capacity of external feeders serving the area as noted in Table IX of the paper. For example, the initial firm capacity of the radial system is 5,000 kva (1 bank) plus 2,500 kva permissible overload plus 3,000-kva radial feeder capacity from outside the area.

The firm capacity of the network is determined by assuming 1 transmission feeder out of service and a permissible load of 2,800 kva on each network unit remaining in service. This figure is determined by allowing 25 per cent emergency overload plus 300 kva for 10 deg C ambient in addition to the 2,000-kva continuous forced-air-cooled rating of the standard network unit, and is somewhat more conservative than the 50 per cent emergency overload permitted on the radial substation.

It may be noted in this case that the firm capacities of both the radial and network systems substantially are greater than the predicted load throughout the 10-year period. Such a condition always is necessary with a radial system since the initial installed capacity must necessarily be large and succeeding increments in capacity must likewise be large. However, in most cases, it will be found that the network can follow the load curve much more closely than was found to be permissible in the present case. For example, in many cases similar to this one, the 2 initial units would have been easily adequate up to 1934, 4 units would

have been adequate from 1934 to 1937, 6 units would have been adequate up to 1939, and 8 units would have been adequate through 1941.

Thus, Mr. Wulfing might easily have found in making this study that—with identically the same assumed load growth, but with a somewhat different layout of existing equipment—the ultimate network would have consisted of 8 units instead of 10, and 2 transmission lines instead of 3, and the carrying charges would have been considerably reduced owing to the delayed installation of the 8 network units. These combined savings would show the network economically to be considerably more attractive than the radial system.



Predicted 10-yr load growth, showing also growth in firm capacities of proposed network and radial systems

An alternative layout might have been adapted permitting still greater savings in some cases. For example, the third transmission line might have been installed in 1937 or 1938 instead of 1939. The 6 initial units could be fed from these 3 lines (2 per line) giving a network firm capacity of 11,200 kva (in addition to any external feeder capacity which may still exist in the area), which is adequate to care for the total load throughout the 10-year period. Although, in Mr. Wulfing's particular case, 10 units were necessary, it is evident certainly that in many cases 6 units would have been adequate for a similar load area.

In regard to distribution system economics, I should like to emphasize one further factor which may result in considerable savings for the network but which cannot be evaluated in an estimate.

Referring to the load curve again, suppose that the radial system had been adopted and developed as planned up to 1935. At this time the third transformer bank will just have been installed. Even though the load should grow as rapidly as predicted, this third bank will constitute unused capacity for several years to come. But suppose the load should stop growing or fall off at this time—an occurrence which experience has shown may very well happen. In this event a heavy and unnecessary investment in substation capacity must be carried.

Had the network been adopted, it would have developed in small increments and its expansion could have been curtailed at any time the load stopped growing thereby obviating unnecessary capital expenditures.

I am bringing up these points merely to emphasize the fact that generalized conclusions in regard to distribution system economics certainly cannot be drawn from the results of an isolated study.

Fundamentals of Design of Electric Energy Delivery Systems

Discussion of a paper by J. Allen Johnson and R. T. Henry published in the December 1933 issue, p. 831–8, and presented for oral discussion at the power distribution session of the winter convention, New York, N. Y., Jan. 25, 1934.

C. A. Corney: We are indebted to Messrs. Johnson and Henry for their valuable suggestions for the standardization of terms, to be used when dealing with supply systems generally. Much of benefit would result if these or similar terms should be generally used.

The first part of this paper is concerned with what may be referred to as the "fundamental principles" which any distribution system should adhere to in order that it may satisfy the requirements of a proper economic balance. With these principles the writer believes we can all agree. The latter part of the paper describes the radial system adopted in Buffalo after comparison with a primary network system. One of the authors in the *Electrical World* article mentioned in the paper gave a more detailed description of the radial system adopted and expressed doubt as to the suitability of the network system, as developed at that time, with reference to regulation, instability between units, and relaying. It was stated also that the cost of the network system was found at the time of their study to be at least 10 per cent greater than the radial system adopted. The present paper indicates that a network for this area would be 36 per cent greater in cost than the radial system adopted. It would be of interest to have the reasons for this rather wide difference in estimates more fully explained.

Since the Buffalo system was completed, the Boston Edison Company has put into successful operation a primary network using standardized factory built units. Regulation is entirely satisfactory; instability is prevented by reversed reactance connections on line drop compensators and a rising voltage characteristic is readily obtained to overcome drop in mains, distribution transformers, and their secondaries. Relay operation has been very satisfactory, experience having been gained with faults on both the transmission system and on the distribution mains. In all cases relay operation has been correct.

In the matter of cost, it would seem that, for Buffalo conditions where densities run up to 5,000-kva per square mile, the selection of network units as small as 1,500-kva capacity was not well advised as it would appear that 3,000-kva units would have been more suitable. The writer knows of no reasons why network transformers cannot be standardized in larger capacities, also using the same switching unit as at present developed. The cost of a single 3,000-kva network unit would on this basis only be about 16 per cent greater than for a 1,500-kva unit.

Had such larger units been considered, it would appear from a brief study of Table II of the paper that with the fewer units required and the less mileage of subtransmission cable needed the cost comparison would have been much more favorable to the network, if indeed the network might not have cost less than the radial system.

The writer feels that the costs of the Buffalo radial system must have reflected the savings attendant upon quantity purchase and installation of so many units of the same type at the same time and using but one set of drawings. In the usual case a radial system is expanded piecemeal with attendant higher costs.

The authors refer in the paper to 2 particular difficulties which they found in attempting to apply the primary network scheme, one being the unfavorable effect on firm rating factor of the network caused by irregularities in the area such as parks, waterways, railroads, etc., and the other, of obtaining uniform loading of network units on account of the impedance in the network. Concerning the question of the effect of irregularities in the area, it is difficult for one unfamiliar with local conditions to see how the network need suffer in that respect in comparison with the radial system. It is not always necessary to have network mains supported at both ends, so that long stretches of mains crossing park or other territory in which there is no load are uncalled for. In the Boston network there are

numerous radial branches from network mains and several cases where short radial feeders run directly from network switches without being tied in to another network unit at the far end.

Concerning the uniform loading of units, we have had absolutely no trouble in this respect, being able by adjustments of the line drop compensators to divide kva load very satisfactorily. Mr. T. H. Haines will later present test data on this feature.

It is of course to be expected that with non-uniform and variable loading conditions in an area, network transformers will not be loaded exactly alike at all times, anymore than it would be possible to load the various stations in a radial system with exactly equal amounts of load.

The authors refer to the facility with which load can be transferred from one station to another. In order for this to be done readily an overloaded station must have an underloaded one adjacent. As adjacent stations are on the average about a mile apart and as network units would be much closer together than this, such a condition of loading in a network system automatically would adjust itself by nearby units picking up load from units which tended to become overloaded. In neither system can spare capacity at a distance from an overloaded section readily be made use of. Additional capacity must usually be added in either case at or near the heavily loaded or overloaded area.

In the cited case of uniform load growth over the entire area it seems to me that in the radial system transformer units and additional feeders would have to be added throughout the area in exactly the same manner as additional network units and mains would be needed throughout the area. I see no advantage of the radial over the network system in a case of this kind.

A very excellent analytical study of the question of load division and regulation in large and small networks under various loading conditions both normal and abnormal was made by Mr. F. M. Starr of the General Electric Company and reported in his paper presented at the Chicago A.I.E.E. Convention in June 1933, (Theory of Primary Networks, Trans. A.I.E.E., Sep.–Dec., 1933, p. 934–42). The analytical studies were checked by tests on actual networks and by the use of the calculating table. This paper concludes in one place that "the loss of a transmission feeder in a network of fairly large size need never impose an excessive overload on any transformer." The paper further indicates that satisfactory emergency loading conditions may be obtained without the necessity of interleaving transmission feeders.

Messrs. Johnson and Henry go into some deatil to describe desirable features of their system without stating clearly that many of these also are possessed by the primary network in some cases to a greater degree.

Some of the more important points claimed for the radial system which are common to the network are as follows:

1. Uses small substations closely spaced.
2. Has short distribution feeders and eliminates the need for carrying main feeders to load centers and providing radial branches from there.
3. Utilizes bus regulation.
4. Develops low short circuit currents.
5. Provides freedom in the choice of location on account of small size.
6. Has no high voltage bus or switching equipment.
7. Provides simple compensation for line drop.
8. Faults in subtransmission, transformers, or regulators are isolated without interruption.
9. Secondary network units also may be supplied from the same transmission circuits.
10. Industrial and lighting loads may be served from the same feeders.
11. Industrial customers of moderate capacity may be served by separate 4-kv feeders.
12. Large industrial customers may be served direct from subtransmission circuits, or substation or network units installed on customers' premises. This later plan has been carried out in one case on the Boston system.
13. Load may be shifted from heavily loaded subtransmission circuits to a lightly loaded nearby group.

The foregoing features are all possessed by the network. In the opinion of one who has been able to observe operating conditions with both radial and network service, the network provides inherently a higher degree of continuity, better regulation, lower losses, greater ability to start motor loads without flicker and greater flexibility in providing for load growth and for changes in area load centers. The writer believes the network will in many instances also prove itself in the matter of cost per kw of load carried over a period of years.

T. H. Haines: Soon after the installation of the primary network supplied from 3 transformer units on the Boston Edison System, a series of tests was made to determine the division of load between the 3 units. It was found that under light load conditions when the network was taking about 1,150 kw of load, unit 1 carried 30.2 per cent of the load, unit 2 carried 35.3 per cent of the load, and unit 3 carried 34.5 per cent of the load. Similar tests made under full load conditions of 2,850 kw showed that unit 1 carried 33.5 per cent of the load, unit 2 carried 32.7 per cent of the load, and unit 3 carried 33.8 per cent of the load. A complete description of the Boston network layout was given in an article by Mr. A. H. Sweetnam (4-Kv Network Saves 20 Per Cent, *Electrical World*, March 14, 1931, p. 500–3). It should be noted when referring to the article that the Boylston Street unit 4 is not yet in service.

A very good indication of the manner in which the load divides between the 3 network units is given by Table I which gives the total kilowatthours delivered to the network for the year ending January 2, 1934.

Table I

	Kilowatthours			
Unit	Aφ	Bφ	Cφ	Total
1	1,172,800	1,185,000	1,330,200	3,688,000
2	1,439,600	1,413,800	1,316,700	4,170,100
3	1,231,500	1,258,800	1,234,200	3,724,500

This shows that unit 1 supplied 31.8 per cent of the total kilowatthours, unit 2 supplied 36.0 per cent and unit 3 supplied 32.2 per cent. These figures show that unit 2 carried a slightly higher percentage of the total load than the other 2 units. This is explained by the fact that unit 2 supplies a radial circuit directly from the bus in addition to the network ties to the other 2 vaults.

The kva likewise is controlled easily by the line drop compensators so that all the units will operate at very nearly the same power factor.

A few months after the network had been in operation, a case of system trouble developed which caused the transmission lines feeding units 1 and 3 to trip out of service. The reverse energy relays at these units operated successfully clearing the network transformers from the faulty transmission lines thereby causing the entire network load to be thrown on to unit 2. As it so happened, this trouble occurred in the forenoon when there was only about 2,000 kw of load on the network, so unit 2 was able to carry this load with very little drop in voltage as may be seen from the following readings obtained from the recording meters in the 3 units.

At about 9:45 a.m., the recording ammeters at all 3 units went off scale, and immediately units 1 and 3 dropped out, while the ammeter at unit 2 dropped back to a position indicating the total load of the network at that time. Simultaneously, the voltage on all 3 units dropped to zero from approximately 120 volts and immediately came back to 112 volts at unit 1, 118 volts at unit 2, and 116 volts at unit 3.

The network operated in this manner for approximately a half-hour until it was possible to return units 1 and 3 to service.

There have been only 2 cases of breaker operations on the 4-kv network mains since their installation, and in both instances the relays operated successfully to clear the fault.

The first operation was caused by 2 primary wires being down in an overhead section of one of the network mains causing 1 breaker operation, and upon reclosure the circuit stayed in for 5 minutes; then another breaker operation occurred and upon this reclosure the circuit stayed in until it was taken out for repairs.

The second operation was caused by the breakdown of an overhead sectionalizing oil switch. In this case the circuit breakers at each end of the affected main reclosed 3 times and then locked out. The effect of the total of 6 reclosures was rather disastrous to the switch. We have since reduced the number of reclosures possible.

In conclusion, therefore, it may be stated that all relay operations have been entirely correct to date, as all troubles, both on the 13.8-kv and on the 4-kv systems have been successfully cleared.

G. O. Eaton: In 1931 the Malden Electric Company installed 2 medium voltage network units in Medford. These have since been operating as radial substations and have proved satisfactory in all respects.

This installation has demonstrated the adaptability of the net work plan for meeting changing load conditions. When the existing 2 units were installed the load was growing rapidly and the installation of 2 additional units was planned for the next year. The expected load growth did not materialize and the original units still are able to take care of the situation.

If, in 1931, a conventional radial substation had been built rather than to install network units a comparatively large initial investment in land, building, and transformers would have been made during the

following years of unexpected restricted growth would have been but little utilized. It is estimated that the initial substation investment would have amounted to about twice as much as was spent on the network system. It will be seen, therefore, that substantial savings in capital costs have been made.

C. M. Gilt: Messrs. Johnson and Henry are very fortunate in having had the opportunity to design and install a new 60-cycle distribution system and are to be complimented on the very complete analysis they have made of the whole problem. All too frequently our electrical systems grow by piecemeal additions based upon piecemeal analyses. No doubt we would often save money in the long run, and provide better over-all service by adopting and then following a consistent plan of development as a result of a complete analytical study rather than adopting what appears to be the best expedient for each move.

It is interesting that Messrs. Johnson and Henry have arrived at the same general conclusions and therefore somewhat confirm the conclusions at which we arrived in Brooklyn in studying our distribution problem, which are that secondary networks best meet the needs in high load density areas, and the radial system best satisfies the lighter areas. We can go one step further and say that for the types of loads and load densities we have studied, the low voltage network not only gives the best service but is the cheapest installation wherever the distribution system must be underground. Of course, a secondary underground network cannot compete in cost with an overhead radial system. The underground network gives better continuity than the radial system, yet the continuity of a good radial system is such that in general one cannot justify very much more money for improved service to the average consumer. Our records over the past 7 years indicate that the average radial customer may expect one outage every $2^1/_2$ years which will last about an hour. The average network customer may expect an outage once every 500 years but it will last nearly 3 hours.

When we redesigned our electrical system in 1922, we did not have equipment available for a low voltage a-c network, the latter having infiltrated and replaced our radial system over the past 7 years. While we omitted from our substations high tension breakers, sectionalized our 4-kv busses and used automatic reclosing feeder breakers, the Buffalo design has gone further in reducing costs and probably has improved service by shortening the 4-kv feeders. I am confident that were we to redesign our radial system in light of our experience and present day equipment we would construct smaller and simpler substations, much as is done in Buffalo. A review of our substation records indicates very few failures within the station and that failures resulting from equipment installed to secure flexibility and continuity may be as embarrassing as failures which would have occurred had there been somewhat less equipment and flexibility.

Certainly we have lost nothing but initial cost and continuing maintenance costs by connecting transformers directly to "subtransmission" cables without circuit breakers. There is no reason why several substation transformers cannot be so connected to one high tension cable. It is common practice to connect many network transformers in this way and we are connecting network units onto our substation feeders without any real detriment.

In discussing generating station switching Mr. Eales advocated a principle of physically separating circuit breakers from the equipment they are to protect, and so applied it to distribution systems and network units in particular that it might well receive some comment at this session. The writer agrees with the principle as an ideal but in application must temper the ideal by the costs it would involve and the results of experience. To separate our network switches from our network transformers by a wall as installed in our manholes, would increase the size of the manholes and cost of installation by over 15 per cent, and sacrifice some of the advantages of a complete factory built unit. In Brooklyn there are over 1,000 3-phase units in operation with the network switch mounted in a box on the transformer tank. Most of these have been in service for 2 years, and some of them for 7 years. During this period we have had 11 failures of transformers or high tension potheads, none of which involved the network switch, and 4 network switch failures that destroyed the switch, none of which involved the transformer. Should a transformer failure involve the network switch, the result would be a secondary short circuit, a condition which we must expect from other causes as well and must be prepared to meet. Therefore we could hardly justify the extra cost were we to follow out this principle in the case of manhole transformers. The condition is somewhat different in the case of transformer installations in vaults in customers' buildings. Here space arrangements and handling facilities commonly dictate single phase transformers with separate network switches and the isolation usually can be obtained at little or no extra cost. The advantages may be slightly greater also, as a short circuit of the network switch may be a failure on the customer's service cables and interrupt service to him rather than a short circuit on the general street network.

A. H. Kidder: The method for discounting the expenses incurred in different years to their "present value" (as used by Messrs. Sweetnam and Corney, and by Mr. Wulfing) is particularly commendable in that it is a device which recognizes logically the important difference between the value of a dollar in hand and the value of a dollar to be saved at some future date. The writer believes this is the first time that economic perspective has been introduced in such papers to allow for the above difference and to allow for progressively increasing uncertainties in estimates of future savings. This is true particularly in the Sweetnam-Corney paper where the values have been discounted at 15 per cent compound interest. During the past few years the writer has found this device to be practically indispensable for summarizing estimated year by year expenses in comparisons between plans which involve varying amounts of changeover expense and different construction schedules.

The Sweetnam-Corney paper also illustrates the way in which some important local considerations may affect an economic comparison which deals with plans for supplementing existing facilities. Two such factors which apparently were beyond the control of the engineers in this instance are given in the following:

1. Take for example the Christmas-stocking shape of the Somerville area and the present substation location over half a mile from the load center. These local factors place the plan for enlarging the present substation under a considerable economic handicap.

2. Also, for instance, a large part of the approximately \$100,000 investment difference between the least expensive primary network plan (No. 7) and the plan for enlarging the existing substation (No. 1) may be due to the fact that the substation is modernized under plan No. 1, and is not modernized under any other plan. The decision that the substation need not be modernized under the network plan may or may not have depended to a considerable extent upon judgment. In any event, this factor might be responsible for a large part of the economy shown by the network plan. In the interest of accuracy, the writer believes some credit should have been given to plan No. 1 for the fact that alone it provides for rebuilding the substation, although it is doubted that this increased accuracy would have any important effect upon the conclusion reached.

The writer is becoming more than ever convinced that no distribution system yet developed holds sufficient promise to justify abandoning intensive search for a system in which the cost per unit inherently lies in a much lower order of magnitude than is being found in the systems analyzed to date, where the margin of economy is narrow. It is important to realize, however, that such a system, if discovered, probably would be installed more or less piecemeal as required by load growth and its effect upon primary distribution system costs as a whole might not become impressive for 10 or 15 years after adoption of the plan.

Opportunities for economy in present systems must not be overlooked in the search for new methods. This is true particularly since such economies might be appreciable and probably few years would be required to realize their maximum benefits. For instance, it is very probable that present substation and distribution facilities can be operated safely at loads considerably higher than at present.

Under normal loading conditions, with all the capacity in service, the loading of the substation and distribution facilities may be increased very appreciably without allowing operating temperatures to exceed present conventional limits.

Emergency outage of one unit at the time of the peak in the year when the peak would be comparable to the total capacity installed is, on the average, a very remote contingency indeed. At its worst this would involve only a few hours' operation at unconventional temperatures. It is probable, however, that most of the facilities now used can be subjected to such an emergency condition as often as 1 to 5 times during their useful life, without noticeable effect upon their life, and with negligible effect upon appropriations to reserves for renewals and replacements. From the service point of view, such an emergency probably would have no more serious consequence than perhaps the delivery of voltage slightly below normal during the 1 or 2 hours duration of the most severe condition.

If some such schemes are found to be practical, their benefits will accrue almost immediately and may add measurably to the difficulty of finding more economical, new methods for primary distribution.

News
Of Institute and Related Activities

Many Sections and Branches to Celebrate the Institute's 50th Anniversary in May

SECTIONS of the Institute throughout the country as well as many Student Branches are now actively formulating plans for the celebration of the Institute's 50th anniversary during May 1934. Many of these celebrations will be held jointly between Sections and Student Branches.

To assist those who may not already have formulated definite plans, the following summary of what many Sections and Branches are doing is given. Although many of these plans were still in the formative state at the time this issue went to press, the ideas contained herein may prove valuable. The following paragraphs are taken directly from the plans submitted by the different Sections and Branches, and are, of course, subject to revision.

University of Alabama Branch. Plans to observe the 50th anniversary by holding a joint meeting of the Birmingham Section and the Student Branches of Alabama Polytechnic Institute and Mississippi State College. A feature of this meeting is expected to be an address from the oldest Institute member available in the District.

Baltimore Section. A dinner meeting in May has been tentatively decided upon, to which appropriate speakers will be invited. The arrangements for this meeting have been assigned to an entertainment committee which is now active.

Chicago Section. A celebration meeting during May is contemplated. It has been the custom of this Section to have a smoker each year, usually during the spring season, and at which a larger percentage of the members is in attendance than at any other meeting during the year. It is planned to combine the celebration meeting and the smoker in 1934 in the hope of getting out as many of the members as possible, especially those who have a knowledge of the early history of the Institute. It is hoped that through this arrangement appropriate celebration ceremonies can be conducted.

Cleveland Section. The annual meeting customarily held by this Section in May is being extended this year to make a fitting 50th anniversary celebration. The meeting has been arranged so that Doctor Whitehead may be present as the speaker. It is intended to invite representatives of other engineering societies to attend, and the Section also hopes to coöperate with the Branch at Case School of Applied Science.

University of Denver Branch. A program in honor of this celebration is expected to be included in the May meeting. It is expected that the history of the Institute will be reviewed with special attention to the outstanding men who have been responsible for its continued success, and also that there will be presented a history of the progress of the electrical industry through this period, showing the relation of the Institute to this progress.

Erie Section. Provided that more elaborate ceremonies for celebration of the 50th anniversary are not arranged, it is possible that some special anniversary features will be incorporated in the special ladies' night which is scheduled for May 15.

University of Idaho Branch. As May is the regular month and year in which the biennial engineering show is held, every effort is being made to have the Student Branch take an unusually active part in this show and emphasize in its display the fact that this is the 50th anniversary of the Institute. Although plans have not yet been crystallized, a large enthusiastic student meeting has been held and some 30 different projects are under way. The fact that this is the 50th anniversary will be made an emphatic idea of the show.

Indianapolis-Lafayette Section. The anniversary meeting will take place in the latter part of May and is planned as a social meeting to celebrate the Institute's 50th anniversary and to close the season's activities for this Section. A golf tournament and other outdoor activities are planned for the afternoon, followed by a dinner at which a speaker of prominence will give a history of the Institute and the men who have been active in it since its organization.

University of Kansas Branch. A combined meeting is being held with the Kansas City Section to celebrate the Institute's 50th anniversary. The program for this meeting is in the hands of the Section's program committee. Engineers who were in active practice during the early days of the Institute will probably be secured as speakers.

University of Louisville Branch. A joint meeting of the Louisville Section and the University of Louisville Branch is being planned. The students will present papers pertinent to the occasion, and special demonstrations will be given.

Lynn Section. A banquet will be held in Boston, Mass., on April 7, at which mention of the 50th anniversary will be made. An effort will be made to have as many of the charter members of the Institute as is possible attend this banquet.

Minnesota Section. The meetings and papers committee of this Section has scheduled a discussion of the matter of celebrating the 50th anniversary, and definite plans will be made. It is felt that the anniversary should be recognized in some appropriate way and the Section plans to exert great effort in trying to make this event an outstanding one in the history of the Minnesota Section.

Mississippi State College Branch. This Student Branch plans to join with the Student Branches of the University of Alabama and Alabama Polytechnic Institute in a joint celebration with the Birmingham Section.

Montana Section. The Montana Section and the Montana State College Branch are planning to hold a joint meeting in Bozeman, this meeting to include a lecture and banquet.

University of Notre Dame Branch. Tentative plans at present include the holding of an open meeting of this Branch to which the entire university and the public will be invited. At this meeting some outstanding electrical demonstration will be presented, probably in conjunction with the research laboratory of an industrial organization. Other plans will be formulated later.

Ohio State University Branch. Although plans of this Branch for the 50th anniversary celebration have not yet been definitely formulated, it seems most probable that the Branch will join with the Columbus Section in this enterprise.

Oklahoma City Section. It has been decided to have a one day joint meeting of the Oklahoma City Section and the Student Branches of the Oklahoma Agricultural and Mechanical College and Oklahoma University. The technical part of the program will consist of papers by students from the 2 colleges and members of the Section. The meeting will be concluded with a banquet in the evening at which it is expected a speaker who is a nationally prominent Institute member will be present, and who will give an appropriate address. The details of the meeting are being worked out by the meetings and papers committee of the Section.

Oklahoma Agricultural and Mechanical College Branch. It has been the custom for this Branch to have a joint meeting with the Student Branch of the University of Oklahoma in May, under the sponsorship of the Oklahoma City Section. Although this meeting has taken place alternately on the 2 campuses, it has been decided for this year to merge the joint meeting with the anniversary program and to hold the meeting in Oklahoma City in order that a larger portion of practicing engineers might attend. The student sessions will be held in the morning, at which a paper presented by a representative of each of the 2 participating schools will be presented. This will be followed by a luncheon at which visiting electrical engineering students of both colleges

will be guests. At the Section meeting in the afternoon, 2 papers are to be presented. This will be followed in the evening by a dinner meeting. It is likely that the meeting will take place during the first half of May.

Pittsfield Section. An anniversary banquet is being planned for May. Details are now being arranged.

Providence Section. The program committee of this Section has made tentative plans for an outing to take place in May. This will be held on a Saturday afternoon and evening, the afternoon being given over to sports with a dinner in the evening, with an appropriate speaker. In this way it is hoped not only to celebrate the Institute's 50th anniversary but also to create a feeling of better fellowship among the individual members of the Section.

Rose Polytechnic Institute Branch. A combined meeting of the Branches of Purdue University, University of Illinois, and Rose Polytechnic Institute, and the Indianapolis-Lafayette Section is being planned for either April 14 or April 21 at Rose Polytechnic Institute. The program is to consist of papers during the morning, with a luncheon program, followed by inspection trips in the afternoon.

Rutgers University Branch. The Student Branch is planning a joint meeting with the Newark Institute of Technology Branch, which will be held at Rutgers University. It is hoped to have one of Mr. Edison's laboratory assistants present some of his experiences in connection with the early developments of electricity.

San Francisco Section. As the 50th anniversary of the founding of the Institute is the 30th anniversary of the founding of the San Francisco Section, it has been proposed that these 2 events be celebrated at the same meeting. A possible feature of the program is a dramatic sketch portraying the founding of the Institute, featuring as characters several charter members of this Section. The selection of an appropriate paper from one of the early A.I.E.E. TRANSACTIONS also is being considered, this paper to be read and discussed by different members of the Section, who will play the parts of the original author and discussors. It has been suggested that a Student meeting be arranged for the afternoon, with the anniversary meeting in the evening.

University of South Carolina Branch. It is planned to celebrate the Institute's 50th anniversary with a banquet in May. The speaker is to be Prof. Thomas F. Ball, counselor of the Branch, and his speech will center around the founding of the Institute and its history. The banquet will be arranged in every way to bring out the main theme of the anniversary. If funds permit a large cake with 50 candles will grace the center of the banquet table.

Semiannual Meeting of The A.S.M.E. The semiannual meeting of The American Society of Mechanical Engineers will be held in Denver, Colo., June 25–28, 1934, at the Cosmopolitan Hotel. The tentative program, which has been provided by the Colorado Section of the society, contains technical sessions covering machinery and management developments. Papers are promised on recent mechanical engineering developments in mining, fuel utilization, sugar refining, humidity, and management. A group of inspection trips to plants and mines is being arranged.

North Eastern District Meeting to Be Held in May

The meeting of the Institute's North Eastern District, No. 1, will be held this year in Worcester, Mass., May 16–18, 1934. In addition to arranging satisfactory technical sessions, considerable attention is being paid to student participation in the meeting. In arranging sessions and inspection trips, the interests of both groups, namely, active members and Students, are being considered.

The papers being arranged for discussion at the Worcester meeting are to be based largely upon papers recently published in ELECTRICAL ENGINEERING, supplemented by special subjects and items of local interest.

1934 Yearbook Now Available

The Institute's Yearbook, not published since 1931, is again being published this year and contains a complete listing arranged both alphabetically and geographically of names and addresses of all members (correct to January 31, 1934), a copy of the by-laws and constitution, a list of Institute officers and committees, as well as other information of interest in Institute activities. This Yearbook is now available for distribution.

It is the definite policy of the Institute to protect its members against the promotional activities of those who might use the Yearbook for commercial advantage. The earnest coöperation of all members is therefore requested to prevent the use of this Yearbook for advertising or circularizing purposes. Any such action must be considered as outside of its field of application, and as absolutely prohibited.

Large Electrical Equipment Orders Placed

Following announcement that the electrification of the lines of the Pennsylvania Railroad from Wilmington, Del., to Washington, D. C., will be completed, contracts aggregating over $1,250,000 for major electrical equipment were let by the Safe Harbor Water Power Corporation and the Pennsylvania Water and Power Company. Power for the electrification from the Susquehanna River to Washington will be supplied by these 2 companies and by the Consolidated Gas Electric Light and Power Company of Baltimore, known as the Aldred group.

These equipment contracts were divided between the General Electric Company, the Westinghouse Electric and Manufacturing Company, and others. The equipment will be ready for delivery of power before the end of 1934.

The orders call for the delivery of the largest single-phase waterwheel generator ever built in this country. This generator which will have a capacity of about 31,700 kw, will be especially designed for railroad supply, and will be installed in the hydro-

Glareless Lights for St. Paul Airport

LIGHTING especially designed to eliminate stray vertical light which acts to obstruct an aviator's vision and impair his view of the landing field has been installed at Holman Field, the airport at St. Paul, Minn. The 3,000-watt floodlights used have 45 and 25 deg lenses. Three banks of 2 floodlights mounted on 28-ft platforms supported by pipe standards comprise the major part of the runway lighting. Two obstacle markers are mounted above each bank as a warning to low flying aircraft. Also, the hangar apron is lighted by 250-watt floodlights. The floodlighted apron is shown in this view, the lighted runway being in the distance. This equipment was manufactured by the Westinghouse Electric and Manufacturing Company.

electric plant at Safe Harbor. Included also in the contract is a frequency changer of approximately 26,000-kw rating. Transformers, substations, and transmission lines will be constructed by the power companies, and later, an additional power supply requiring an outlay of upwards of $1,000,000 will be provided by the Consolidated Gas Electric Light and Power Company. Exclusive of the contracts for electrical equipment recently placed, expenditures of the 3 power companies in connection with this electrification will be upwards of $4,000-000.

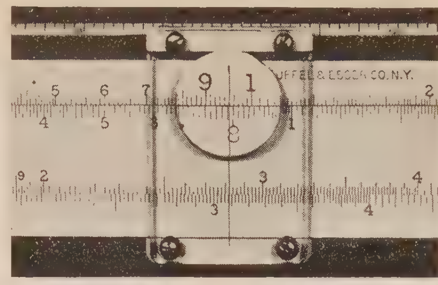
Future AIEE Meetings

North Eastern District meeting,
Worcester, Mass., May 16–18, 1934

Summer convention,
Hot Springs, Va., June 25–29, 1934

Pacific Coast convention,
Salt Lake City, Utah, Sept., 1934

New Slide Rule Magnifier



A small slide rule magnifier which incorporates certain advantages not available in other slide rule magnifiers has been patented by H. P. Clausen (A'03, M'03). This magnifier, being spherical in shape, with a flat bottom, magnifies the scale quite evenly and brightly in all directions. As there is very little distortion the magnifier does not need to be centered on the hair line. The magnifier is attached to the glass runner of the slide rule by suction and can be changed in position when desired. As it covers only one scale at a time, the other scale is left free for ordinary work. It magnifies the scale to about twice actual size. Further information can be obtained from R. D. Wadia, 15 Charlton Street, New York, N. Y.

Reports of Committee Meetings Held During Winter Convention

SEVERAL of the general and technical committees of the Institute held meetings during the recent winter convention at New York, N. Y., January 23 26, 1934. A summary of each of these meetings is given in the folowing paragraphs with the exception of the open meeting of the committees on education and Student Branches which was summarized in ELECTRICAL ENGINEERING for February 1934, p. 350, and the following committees for which no reports were made available for publication: research, general power applications, automatic stations, protective devices, production and application of light, and Sections, the sectional committee on electrical definitions, and the standards committee. Activities of the standards committee are reported month-by-month under the "Standards" department of ELECTRICAL ENGINEERING.

Technical Program

A part of the technical program commi tee meeting was devoted to the consideration of programs for the 1934 summer convention to be held in Hot Springs, Va., June 25–29, 1934, the Pacific Coast Convention to be held in Salt Lake City, September 1934, and the 1935 winter convention. The number of technical sessions for the summer convention program was limited to not more than 6, in order to allow ample time in the afternoons for sports, recreation, and other activities. The subjects which were tentatively suggested for the summer convention program are as follows: education, insulators, power generation, automatic stations, electrical machinery, electrical measurements, communication, and general power applications. For the Pacific Coast convention program members of the committee were asked for suggestions and a session on lightning was proposed. For the 1935 winter convention tentative plans are in progress for a symposium on recent vacuum tube developments and a session on illumination.

The methods of conducting some of the winter convention sessions were analyzed to gain the benefits from actual experience. The trial at the power transmission session to present papers by title only, in order to allow more time for discussion, was reported to have been very satisfactory. It also was suggested to be helpful if the presiding officers would ask for a showing of hands at the beginning of a meeting to determine the number of discussors and proportion the time accordingly. In general, it was believed that there should not be a fixed rule regarding the method of conduct of technical sessions but shorter presentations with the authors stressing the cardinal points in their papers and strict limitation of discussors to 5 min each seemed desirable.

Members of the committee were asked to expedite the early preparation of papers for the summer convention program. The editor also reported that many requests for the early publication of winter convention discussions had been received, and the members of the committee also were asked to complete the reviews of these discussions without delay. The committee voted to congratulate and thank the editorial department for their efforts in publishing in advance all winter convention papers.

Communication

In line with views expressed at a recent meeting of the technical program committee to the effect that the Institute should give more attention to the subject of electronics, the committee on communication probably in coöperation with other interested committees, is tentatively planning to sponsor at the 1935 winter convention one or more sessions devoted to the subject of vacuum tubes. A considerable part of the discussion at the meeting of the committee was concerned with the plans being made for this program. The outlining of proposals for a group of papers dealing comprehensively with this subject is in the hands of a special subcommittee that has been formed for this purpose. The subcommittee has been asked to make its report and recommendations before the next meeting of the committee in March.

This subcommittee is also part of a group which is considering means of insuring adequate consideration of the subject of electronics in the technical programs of the Institute, including the desirability of a permanent technical committee on electronics. In this capacity the subcommittee is acting under the direction of the chairmen of the committees on electrophysics, electrical machinery, and communication to whom the job of recommending ways and means for most effectively handling the subject of electronics has been assigned by the technical program committee. There was an active discussion of this question at the communication committee meeting.

It was decided to request a session at the summer convention. For this session it is proposed to select the best from a number of papers which will be available at the time rather than to have a group of correlated papers or a symposium dealing with a single topic.

There was also discussion of a statement prepared at the request of the technical program committee outlining recommendations as to the scope of the committee's activities.

The annual report of the committee was discussed and each member was asked to prepare and send to the chairman a brief statement dealing with the technical advances made during the year in the branch of the communication art with which he is familiar. These statements are to be incorporated in a draft of a report to be circulated for comment.

Electrical Machinery

At a meeting of the electrical machinery committee reports of the subcommittees were read and a tentative list of papers for the summer convention at Hot Springs was approved.

A resolution was passed to recommend to the National Electrical Manufacturers Association that in drawing up the test code for induction motors, when tests for efficiency are to be required, the load losses be obtained by measurement and not to be included by an empirical factor.

It was reported that it was expected the final draft of the synchronous machine

test code was about ready for presentation to the standards committee and that the test code for d-c machines had been circulated to the members of the subcommittee for comments.

Electrochemistry and Electrometallurgy

At the meeting of the committee on electrochemistry and electrometallurgy, plans for continued activity in the line of meetings and papers were discussed. It was agreed to encourage papers relating to products of the electrochemical and electrometallurgical industries, especially those having application in the field of electrical engineering. The committee hopes to be able to present a symposium of such papers at a future meeting.

Discussion of the papers presented in the symposium on electric furnaces sponsored by this committee indicates the need for standardization of electric furnace ratings as well as a need for closer coöperation between electric furnace manufacturers, users, and power companies on the difficult problem of load characteristics and power rates. Among the future activities of this committee will be listed a consideration of these problems in coöperation with other committees interested.

Members of the committee expressed their commendation on the action of the board of directors in passing the resolution requesting adequate support for the standardization and research activities of the Bureau of Standards in the electrical field.

Power Generation

The items with which the committee on power generation were primarily concerned at their meeting were: first, the character of the committee report to be submitted at the summer convention; and, second, the survey of the field for available papers for publication in Electrical Engineering and for inclusion in the program for the summer convention.

With reference to the first, it was decided to follow the former procedure of the committee and prepare only on alternate years a comprehensive report covering the activities of the subjects within the scope of the committee. Since such a report was submitted and published last year it is expected that this year's report would not much more than cover the activities of the committee probably touching only the high spots of the past year.

With reference to the second subject, it was decided that the material prepared and submitted in tentative form by the subcommittee on water power survey would be reviewed by members of the committee with the thought of arranging for its presentation at the convention.

It was also decided to arrange for presentation at the same convention session a paper covering those problems which have become acute in the operation of large systems, such as the control of phase angle between bus sections and stations, load control, and the automatic control of frequency.

Other subjects for papers were discussed and capable authors suggested. These will be solicited to prepare papers for future publications.

Power Transmission and Distribution

The annual meeting of the committee on power transmission and distribution as a whole was held to receive reports of activities and plans from each of the subcommittees and to discuss the program for the annual convention at Hot Springs, Va., next June and the Pacific Coast convention at Salt Lake City in the fall.

The subcommittee on lightning and insulators reported progress on the standardization of preferred test waves and showed great progress in uniformity of impulse test results made by the various laboratories. Need for further 60-cycle test data was also mentioned as well as the need of more operating experience on lines protected by counterpoises, values of current in lightning strokes and the value of wood as an insulator. Sessions of 6 papers for the annual convention on insulators and 5 papers for the Pacific Coast convention on lightning were recommended.

The subcommittee on distribution reported that the main result of their work during the past year was the entire technical session held on January 25 on the subject of distribution, and distribution economics. More papers will be available on this subject and another session on the subject in the near future seems advisable.

The subcommittee on standards reported that their principal work has been in connection with the American Standards Association sectional committee on definitions. New definitions on grounding will be referred to the committee.

The subcommittee on cable developments reported that there has not been much activity in papers on underground cables, due primarily to the fact that there have been 2 recent sessions on cables.

The subcommittee on interconnection and stability factors reported that their activities had resulted in the 4 papers on stability presented on January 24 at the transmission session. There are numerous other papers on stability prepared or under preparation, but what is apparently needed at the present time is more information on actual operation, rather than on theory and calculation.

The subcommittee on steel towers and conductors is divided into 3 groups. Group I, which is concerned with towers, is studying the use of hinged and rigid crossarms, rotated towers and the applications of straight line compression formulas. Group II is studying clearances as effected by normal conditions of service, which involves the study of temperature rise of conductors from various causes. Group III reported on conductor studies, including numerous vibration studies; measurements of energy of vibration; whether the energy is consumed in the cable or the clamp; the question of pre-stretching of cables; correlating the available data on field vibration studies; the development of a vibration counter; laboratory methods of performing vibration and fatigue tests and improved terminal connections for such tests.

Transportation

At the meeting of the committee on transportation it was decided that a session would not be requested at the summer convention as papers in hand or in immediate prospect do not justify such a session.

The committee will, therefore, center its attention on developing papers for the winter meeting a year hence and papers

Generators for Boulder Dam Being Assembled

WORK on the 82,500-kva generators being built by the General Electric Company at Schenectady, N. Y., for installation at Boulder Dam, is in progress. The stator frame for one of these units, each of which will weigh more than 2,000 tons, is shown in process of assembly. As announced in a news item in Electrical Engineering for November 1933, p. 796–7, this unit is scheduled for completed installation early in 1935.

which might be available for this meeting were the chief topic of discussion.

Among the topics suggested for consideration was the possibility of securing reliable information on the amount of electric energy or steam required to heat passenger trains of various types under varying conditions of outside temperature and also variations in the amount of traction power required under varying conditions. Various railroads are to be canvassed to see whether a sufficient amount of information of this type can be secured to warrant preparation of a paper or a series of papers.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or to reject them entirely.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Public Versus Private Enterprise

To the Editor:

Referring to Private versus Public Enterprise (see ELECTRICAL ENGINEERING for April 1933, p. 234–7), Dr. Virgil Jordan's deductions rest upon 2 fundamental assumptions, with both of which the writer disagrees. The first is the doctrine of the profit motive, that worthy men will not exert themselves unless they profit with the correlary that those who profit are in the main at least those who benefit society. I suggest that anyone interested make out a list of say 100 of those who in his opinion have contributed in a large way to our civilization, the great musicians, artists, scientists, yes and engineers, and see how many of them were well rewarded and how many starved. Such a list will dispose quite effectively of the profit doctrine.

The other assumption is that our people are individualists. On the contrary our forte, I believe, is ability to organize as seen in our trusts and monopolies where it appears in its least desirable form. The masses in this country are, I believe, less given to individualistic thinking and action than in other first class nations. And that is where our greatest danger lies just now. A quarter of a century ago the man-in-the-street worshipped our millionaires and great executives, who had risen from nothing. This admiration was quite uncritical, but sincere. These demi-gods of 25 years ago have become today's "stuffed shirts," just as uncritically and sincerely. It is rather immaterial which valuation is the more correct, the danger lies in the inability and unwillingness of the masses to differentiate.

Secretary Wallace in a recent speech reported in *Science* (see also p. 395–402 this issue of ELECTRICAL ENGINEERING) criticized the engineers for their failure to take the existing social structure into account. I think he was right. In the richest country on earth we have one-fourth of our people suffering and in want. We may have the finest factories and the best machinery, but what of it? That is certainly not an aim in itself.

Professor Rautenstrauch has stressed the essential:

> "The second principle is that the relative claim of labor and capital to the goods produced must be adjusted to workable proportions."

I believe it is the first principle also and the *sine qua non*. This is not brought measurably nearer by the engineering council's proposed 40 cents an hour minimum for engineers, as reported in the *New Republic* for January 24, 1934, p. 296.

Yours very truly,

B. F. JAKOBSEN (A '09, M '13)
(Consulting Engineer, Central Bldg., Los Angeles, Calif.)

A Theory Regarding Ionization in Cable Fibers

To the Editor:

No published explanation of the superiority of oil filled over solid type cables does justice to the facts. The usual explanation is that oil filled cable is always perfectly impregnated, whereas solid type cable can be perfectly impregnated only at or above a certain temperature. It is well known, however, to those who have done much experimental work with oil filled cables, that a rather poorly impregnated cable of this type is better able to withstand long application of high voltage than well-impregnated solid type cables. It is therefore obvious that the more constant impregnation of the oil filled cable is not the only factor in the relative lives of the 2 types.

At the time of the Chicago meeting of the A.I.E.E. in 1933, I offered the following theory:

> "If there is any ionization of air in the channels of the paper fibers, it must be in the nature of longitudinal flow of ions, as there is not sufficient radial distance to permit ionization by collison. Here we may, perhaps, give in to the temptation of speculating on what may happen if air in a fiber becomes ionized. A stream of gaseous ions would shoot out of the ends of a fiber of paper into the oil and we may expect different effects according to circumstances. If the oil is in a thin film, as between tape faces, the ions will not get very far. If, however, the oil is in a tape edge channel, the gaseous ions have a considerable free path in which to move. If the oil is thin, these ions will be gradually retarded and absorbed by the oil. If, however, the oil is thick, the gaseous ions will be obstructed and hot spots will be developed. Perhaps a group of fibers shooting ions at one point in the oil may be necessary to start a destructive hot spot. This would explain why dendrite-forming hot spots practically always appear at the edges of tapes."

This material was edited out of my discussion [by technical reviewing committee—EDITOR] without my knowledge, but references to it (*e. g.*, Roper, A.I.E.E. TRANS., v. 52, 1933, p. 1,024) were allowed to remain. It has, therefore, seemed advisable to publish it in order to give some meaning to these references.

The above material, in quotation marks, should constitute a paragraph 20 lines from the bottom of the first column on p. 1,016 of the A.I.E.E. TRANS., v. 52, 1933.

This theory may seem somewhat speculative, but it is not entirely without experimental verification, as I hope to show on a more suitable occasion. Incidentally, if true, it would explain why, according to Dr. Whitehead's curves, it is immaterial what base oil is used in solid type cable, whereas in oil filled cable, the chemical base of the oil may have some significance. In the case of solid type cables, it is the consistency, more than the chemical nature of the oil that counts, whereas in oil filled cable, whatever deterioration may occur depends upon chemical instability under electric stress.

Yours very truly,

WM. A. DEL MAR (A'06, F'20)
(Chief Engineer, Habirshaw Cable and Wire Corp., Yonkers, N. Y.)

Improving A.I.E.E. Convention Sessions

To the Editor:

During the recent winter convention I had the good fortune to attend the session on education. All of the speakers talked very interestingly and loudly enough to be heard anywhere in the room. Each man who gave a discussion announced his name and college or company affiliation clearly. Consequently, I believe the session would have held the interest of any engineer who attended even if education were not his particular line.

On the other hand I found that the technical sessions were about the same this year as in previous years. The man who spoke in an interesting manner, loudly enough to be heard and who announced his name clearly, was obviously the exception rather than the rule. We all realize that engineers in general do not have the speaking opportunities or training which most educators have, but it is not the lack of a polished delivery which is felt by the average man who attends these conventions. It is rather the failure of the speaker to make any attempt to hold the interest of the audience and also his failure to speak so that he may be heard clearly.

Since the new arrangement whereby papers are printed in ELECTRICAL ENGINEERING before they are presented has gone into effect it is not necessary for a man to even try to present all the facts in the original paper. Consequently it would seem that a man in giving his presentation could prepare

an interesting statement of the purpose of his work, some high lights of what he has done and draw his conclusions without reading from his notes verbatim. Using the same line of reasoning a man who is interested enough in a subject to prepare a discussion should feel strongly enough to be able to present his discussion in an interesting manner.

Natural modesty probably prevents many a discussor from announcing his name in a loud voice. Therefore I believe it would be advisable for the chairman of a meeting to require that each man who gives a discussion should present a slip of paper on which are written his name and affiliation so that the chairman could announce clearly who was about to speak. Also, I believe that a body such as the A.I.E.E. should be able to provide a satisfactory public address system so that a man could easily present a paper or discussion in the auditorium and not have to worry about the acoustics at the same time.

If the convention sessions are for the purpose of allowing the experts to assemble and discuss their problems with each other, they are probably a success as they are conducted at present, although they would probably be more successful if conducted in a small room around a table. If the sessions are for us engineers who want to hear what the experts have to say I believe that they fail and I should like to make the following pleas:

TO THE INSTITUTE

1. That a good public address system be provided in the auditorium.
2. That the chairmen of meetings be instructed to conduct the meetings less informally, making sure that the audience knows who is talking.

TO THE READERS OF ELECTRICAL ENGINEERING WHO CONTEMPLATE PRESENTING PAPERS OR DISCUSSIONS AT ANY FUTURE CONVENTION

1. That they be not satisfied to rise and read a mass of data or a tabulation of facts but to concentrate more on presenting the significance of the data or facts, stressing their relative importance and in general try to present the paper in the interesting manner that the usually very interesting subjects deserve.

Very truly yours,

JAMES L. HOLTON (A'30)
(Division Engineer, N. Y. and Queens Elec. Lt. and Pwr. Co., Flushing, N. Y.)

[EDITOR'S NOTE: There is a public address system in the auditorium. However, because some persons seem to object to it, it was not used during most of the convention sessions held in the auditorium.]

Graduate Engineering Study Remote From Industrial Centers

To the Editor:

As a former student of the plan of study initiated by B. G. Lamme, I read with interest the plan of work outlined in the paper "The Pitt-Westinghouse Graduate Program," by Prof. H. E. Dyche and Dr. R. E. Hellmund (see ELECTRICAL ENGINEERING for January 1934, p. 103–8). It probably will be of interest to members of the Institute to outline a plan whereby corresponding advantages may be secured under special conditions with competent graduate students in colleges remote from industrial centers.

Early in 1931 a plan was worked out whereby 4 electric power companies in Oklahoma coöperated with the Oklahoma Agricultural Experiment Station in making a study of rural electrification in Oklahoma. An engineer was employed on a part time basis to carry out the project and write the report. In his spare time he was permitted to carry work leading to a master's degree. Under a suitable arrangement his final report was accepted as a thesis. It was published as Bulletin No. 207 of the Agricultural Experiment Station. The work was highly successful and received wide recognition.

In 1932 Bernard E. Lowe received the Institute's manuscript prize for the best Student Branch paper in the South West District with his paper entitled "Economics of Rural Line Distribution." This paper received recognition to a degree that it was possible to set up a so-called industrial fellowship, with one power company and the Agricultural and the Engineering Experiment Stations coöperating. The graduate program of study was carried out under the active supervision of power company engineers and college professors. The results were published as Bulletin No. 20 of the Oklahoma Agricultural and Mechanical College Engineering Experiment Station under the title "Rural Line Design Investigations."

Under the first plan the student, Earl R. Miller, spent 2 years in earning his master's degree while in the second case it required one school year. In the first case the student was paid for carrying out a project while permitted to earn his advanced degree; while in the second plan a fellowship was underwritten for the study of a field sufficiently comprehensive for a master's degree major.

In both cases the coöperating power companies received results that they were seeking, the college faculty had the stimulus of participation in active industrial problems, the engineering school students as a group absorbed some of the spirit that prevails when active projects are under way, and the holders of the 2 appointments received experience and did work much above that of the average master's degree student.

For this plan to be successful it requires special situations, competent students, suitable problems and willing coöperation of all concerned. Several smaller projects, encouraged in part by the first 2 larger setups, are now under way and the results seem promising to date.

Very truly yours,

A. NAETER (A'23, M'30)
(Head of Department of Electrical Engineering, Oklahoma Agricultural and Mechanical College, Stillwater)

Shunt Wound Neutralized Phase Advancer

To the Editor:

A brief introduction to this type of phase advancer was given in the author's contribution (see *I.E.E. Jl.*, 1931, p. 479–80, and *English Elec. Jl.*, 1929, v. 4, p. 186) to the discussion on "The Theory and Performance of Phase Advancers" (by Rudra and Walker) and the present article concerns itself with the theory of operation in greater detail.

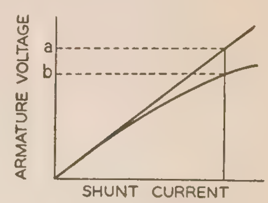
Schmitz (see *E.T.Z.*, 1927, v. 49, p. 1,800 and *E.T.Z.*, 1028, v. 48, p. 1,739) has investigated the problem of the level and overcompensated shunt phase advancer and his solution of the latter type contains a cubic equation which, for practical purposes, is not capable of easy solution. His method of attack of the problem involved the use of trigonometrical equations, whereas the author's solution is arrived at by the use of the operator j, and straightforward algebra. A very simple method evaluating the rotor current at any given slip (except the special case of $S = 0$) both in the motoring and generating region is presented.

LIST OF SYMBOLS

s = fractional slip (+ indicates subsynchronous and − indicates supersynchronous)
E = standstill rotor voltage per phase (star)
X = total motor reactance referred to rotor per phase (star)
R_m = total secondary-circuit resistance per phase (star) of motor including brushes
R_a = resistance per phase (star) of the phase advancer commutating pole, compensating and armature windings, and brushes
A = electromotive force per phase (star) induced in armature per root mean square rotor amperes due to overcompensation of armature magnetomotive force
$K = \dfrac{I_{sh}}{\mathcal{E}}$
I_{sh} = shunt current, root mean square amperes
$\mathcal{E}$ = voltage induced in armature at above current per phase (star)
X_f = field reactance in ohms at full line frequency due to rise and collapse of main flux per pole
B = volts induced in field per root mean square rotor amperes due to over-compensation of armature magnetomotive force = AKX_fs
f = saturation factor = $\dfrac{b}{a}$ (see Fig. 1)
I_r = rotor current per phase (star) also the current per brush of advancer
Φ_a = advancer flux per pole due to shunt current only
R_{sh} = resistance of each shunt field including regulation resistance

The shunt wound phase advancer is provided with commutating pole and compensating windings in addition to the shunt winding. The compensating winding

Fig. 1. The saturation factor, *f*, equals *b* divided by *a*

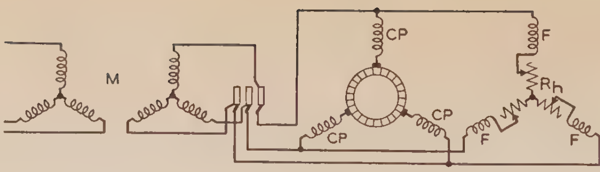


serves to neutralize the armature reaction and the commutating pole winding sets up an excess compensation which ensures good commutation. The armature reaction is thus not just neutralized, but actually overcompensation takes place. This sets up a field proportional to the armature current, and rotating at slip frequency, which induces a leading electromotive force in the armature if the advancer is driven against this field.

Furthermore, this "series" field interacts with the field due to the shunt current to set up a resultant field which determines the phase of the armature induced voltage.

Fig. 2. Diagram of connections

CP = compole and compensating windings
F = shunt fields
Rh = shunt rheostat
M = main slip ring motor



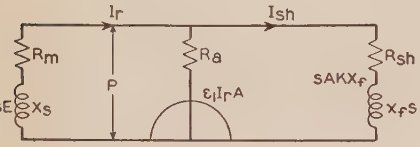


Fig. 3. Equivalent circuit diagram

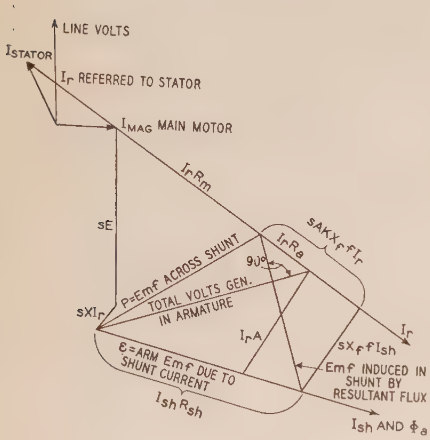


Fig. 4. Vector diagram

The diagram of connections is shown in Fig. 2. In Fig. 3 is shown the equivalent circuit diagram, everything being referred to per phase star. The vector diagram is shown in Fig. 4, in which the drop caused by the shunt current (which is only a fraction of the armature current) across the armature circuit is neglected.

We have

$$sE + \mathcal{E} = I_r[(R_m + R_a) + jXs - jAf] \quad (1)$$

$$P = sE - I_r(R_m + jXs)$$

$$= -\mathcal{E} - jAI_rf + I_rR_a \quad (2)$$

$$= -I_{sh}(R_s + jsX_ff) + I_rsAKX_ff \quad (3)$$

but

$$I_{sh} = \mathcal{E}\,\frac{K}{f}$$

From eq 2 and 3

$$\mathcal{E} = I_r\left[\frac{R_a - jAf - sAKX_ff}{1 - \dfrac{K}{f}(R_s + jsX_ff)}\right]$$

Hence, from eq 1

$$I_r = \frac{sE}{R_m + R_a + jXs - jAf - \dfrac{R_a - jAf - sAKX_ff}{1 - \dfrac{K}{f}(R_{sh} + jsX_ff)}} \quad (4)$$

For any slip or advancer field setting, we can calculate the magnitude and phase of the rotor current and by vector addition with the magnetizing current of the main motor obtain the stator or line current. If we open circuit the advancer field, R_{sh} becomes infinite and we obtain

$$I_r = \frac{sE}{R_m + R_a + jXs - jAf} \quad (5)$$

which will be readily recognized as the series or expedor advancer equation.

If the shunt advancer is level compensated, $A = 0$ and

$$I_r = \frac{sE}{R_m + R_a + jXs - \dfrac{R_a}{1 - \dfrac{K}{f}(R_{sh} + jsX_ff)}} \quad (6)$$

Very truly yours,

R. D. Ball (A'31)
(Y.M.C.A., Forster Sq., Bradford, Eng.)

Applications of Nonlinear Circuits

To the Editor:

I have just read the article titled "Two Applications of Nonlinear Circuits" by T. M. Austin and F. W. Cooper, in the February 1933 issue of Electrical Engineering, p. 293–300. It appears to me that the writers have, in some portions of the paper, confused the saturable reactor control with straight resistance control through auxiliary transformers, and will attempt to justify my opinion by a few comments on individual points in the article.

Messrs. Austin and Cooper state that the decrease of primary impedance of a transformer with increase in secondary current is similar to the decrease with increase in primary current. It is true that there may be some saturation action of the secondary current, but, at least with alternating current in the secondary, the reduction in primary impedance is due simply to transformer action without saturation and occurs at any flux density. The 3-legged reactor shown in Fig. 1 of the article shows the a-c coils connected in series. Although such an arrangement is feasible, much superior operation results from connection of these windings in multiple; both improvement in magnitude of control and reduction of harmonics being achieved.

The scheme shown in Fig. 2 of the article is simply a series resistance adjustment, the 2-legged reactor illustrated acting as a transformer and the net being equivalent to placing a resistance proportional to R in the main line. With d-c supplied to the secondary, some saturation effect occurs but results are much poorer than with the usual 3-legged core: the control being less effective and harmonics being much more pronounced in the former case. In addition the induced a-c voltage in the secondary requires attention. Similar remarks may be made regarding the scheme shown in Fig. 5. Control in this case is wholly due to the negative resistance characteristic of the tube as used. The output is probably rich in second harmonic.

In Fig. 8, the windings indicated on the reactor make it the same as a regular 2-legged transformer instead of the usual 3-legged saturable reactor, and control is not by direct saturation, the main reactor, so called, being merely a series transformer with controlled secondary. The control in this case is very similar to that indicated in Fig. 5 and is subject to the same comments. The actual behavior of the circuit is considerably different from that indicated by the authors. The voltage on the plates of the tubes is not simply that due to the center tapped 220-volt transformer, but has, in addition, the induced voltage in winding B of the auxiliary reactor (or transformer) so that behavior is dependent upon the relative magnitude and phase of the 2 and hence on the power factor of the load.

I must also differ with the authors' statement that hunting is eliminated with these schemes since hunting can occur in purely electrical control schemes as well as with electromechanical arrangements. At no point do the authors indicate how the circuit has been made dead beat. It appears to me that the deciding factor as to hunting with the circuits shown is the characteristic of the load to changes in supply voltage.

Very truly yours,

Samuel Lubkin (A '31)
(Development Engineering, Otis Elevator Co., New York, N. Y.)

A Chart for Complex Quantities

To the Editor:

At the risk of tiring the readers of your correspondence column, I should like to add another item to the list of devices already described (see "Letters to the Editor," Electrical Engineering, August 1933, and subsequent issues) for computing the elements of right triangles. The present device is derived from a complex quantity slide rule utilizing logarithmic polar coordinates which I described in my discussion of Mr. Jesse DuMond's paper on "A Complex Quantity Slide Rule" (see A.I.E.E. Jl., v. 44, 1925, p. 627).

In its simplest form, diagrammatically indicated in Fig. 1, it consists of a chart

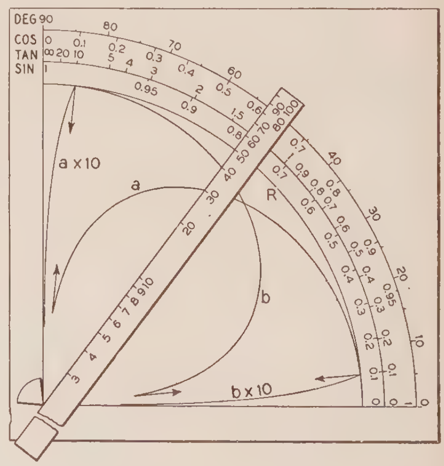


Fig. 1

carrying a knife edge pivot, and of a slide having a logarithmic scale, such as the slide of a discarded slide rule shaved down to a narrow edge, or a transparent rule having a logarithmic scale on its back. A quarter circle of arbitrary radius, designated by R, is drawn on the chart with the knife edge as center, and curves of $\rho = \log \cos \theta$ and $\rho = \log \sin \theta$ are drawn in polar coördinates, utilizing the horizontal radius as origin of angles and taking the circle instead of the center as origin of vectors. As sine and cosine functions are smaller than unity, their logarithms are negative and are therefore drawn radially inward from the circle instead of outwardly therefrom to form curves designated by a and b. The chart may also carry scales giving the value in degrees and the trigonometric functions of the angle comprised between the slide and the radius of reference.

As an example of the use of the chart, let the legs a and b of a right-angled triangle be given, and the length R of the hypothenuse, with the angle θ at the foot of the hypothenuse be required. The slide is moved against the knife edge so as to have the intersection of curve a with the slide read the value of a thereon, and the intersection of curve b with the slide read the value of b. The intersection of circle R with the slide will then occur at a point representing

$$\log a - \log \cos \theta = \log \frac{a}{\cos \theta}$$

and also

$$\log b - \log \sin \theta = \log \frac{b}{\sin \theta}$$

The length represented thereby is therefore:

$$\frac{a}{\cos \theta} = \frac{b}{\sin \theta} = \sqrt{a^2 + b^2} = R$$

the hypothenuse of the triangle. θ is the angle made by the slide and the reference radius. A single setting of the slide thus shows simultaneously all the elements of the triangle, so that any element can be found with the same setting when any 2 other elements are given. In the position shown in the figure, the slide indicates that in a right triangle having legs $a = 30$ and $b = 40$, the hypothenuse $R = \sqrt{a^2 + b^2} = 50$ while $\theta = 53$ deg 10 min, $\sin \theta = 0.8$ and $\cos \theta = 0.6$.

These readings are obtained by one setting without mental calculations, and the solution is clearly visualized as the slide and the reference radii form the same angles as the sides of the triangle. Reading the chart puts no strain on the eye as it carries only 2 curves of which the intersections with the slide stand out clearly. To conserve space the radius of circle R is chosen only slightly larger than one logarithmic unit, so that the portions of curves a and b corresponding to values of $\cos \theta$ and $\sin \theta$ comprised between 0.1 and 0.01 must be shifted radially by one logarithmic unit, and the readings on those portions must be divided by 10.

In the chart illustrated in Fig. 1 the intersections of those portions of curves with the slide lack in precision, but they can be improved to any desired extent by increasing the angular scale of the chart. In the chart illustrated in Fig. 2 a complete circle represents 45 deg, and curves a and b are drawn for values of θ comprised between 0 and 45 deg. For values of θ comprised between 45 deg and 90 deg curves a and b are substituted for each other. To permit swinging the slide over a complete circle, the knife edge of Fig. 1 is replaced by a pin against which the slide is urged, so that the curves must be drawn in coördinates tangential to the pin instead of radially. As a result of the large scale of angles, it is possible to draw curves over a range of radii of 3 logarithmic units giving satisfactory intersections for angles of one degree and even less. Further improvement could be obtained by the use of a nonuniform angular scale varying according to a mathematical law, for example, logarithmically, or changing stepwise at suitable intervals.

Either form of chart illustrated could be converted into a fairly workable complex quantity slide rule by providing it with a pair of slides of transparent material arranged to slide side by side through a pivot member and with suitable radial and angular indicators.

Very truly yours,

D. Journeaux (A'27)
(Electrical Dept., Allis-Chalmers Mfg. Co., Milwaukee, Wis.)

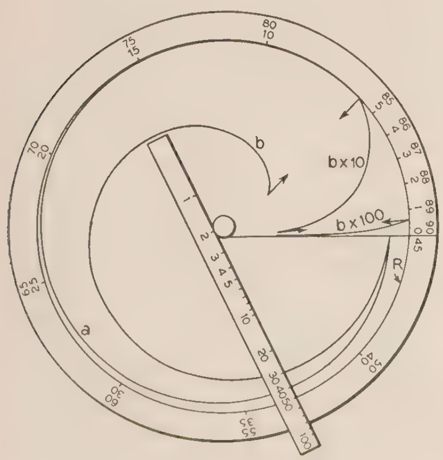


Fig. 2

Personal Items

L. B. Stillwell (A'92, M'92, F'12, member for life and past-president) consulting engineer, New York, N.Y., has been awarded the 1933 Lamme Medal of the A.I.E.E. The medal, which will be presented to Doctor Stillwell at the summer convention of the Institute to be held at Hot Springs, Va., June 25–29, 1934, was awarded him "for his distinguished career in connection with the design, installation, and operation of electrical machinery and equipment." Doctor Stillwell was born at Scranton, Pa., in 1863. He was a student in the Latin-scientific course at Wesleyan University, Middletown, Conn., 1882–4, and took a special course in electrical engineering at Lehigh University, Bethlehem, Pa. In 1885 he received the degree of electrical engineer from Lehigh University. He also has received the honorary degrees of master of science, Lehigh University, 1907; doctor of science, Wesleyan University, 1907; and doctor of science, Lehigh University, 1914. From 1886 to 1891, he was employed as assistant electrician of the Westinghouse Electric and Manufacturing Company, and served as chief electrical engineer of that company from 1891 to 1897. He was an outstanding leader in the development of alternating current, and invented the "Stillwell regulator" for the adjustment of voltage on outgoing lines. Two other inventions which he made and which today are more important, are the "time limit circuit breaker" and the "diagrammatic pilot-control switchboard." He had an active part in the determination of Westinghouse policy with respect to system development engineering and the establishment of 60 and 30 cycles as standard frequencies. His contributions, as Westinghouse engineer, to the general layout and design of the first plant of the Niagara Falls Power Company led to his appointment as electrical director of the latter company, which position he held from 1897 to 1900. Doctor Stillwell began his practice as a consulting engineer in New York City in 1900, and has filled engagements with many companies on large and important engineering projects, including: the electrification of the elevated lines of the Manhattan Elevated Railway Company, 1900–06; Rapid Transit Subway Construction Company, 1900–09; Wilkes-Barre and Hazleton Railway, 1902–05; Hudson and Manhattan Railroad, 1905–13; Erie Railroad electrification 1906; United Railways and Electric Company of Baltimore, Md., 1906–20; Interborough Rapid Transit Company, 1909–20; electrification of the Hoosac Tunnel of the New York, New Haven, and Hartford Railway Company, 1910–11; New York, Westchester, and Boston Railway Company, 1911–15; Lehigh Coal and Navigation Company, 1912–18; New York Municipal Railway Corporation,

L. B. STILLWELL

1913–16; board of economics and engineering of the National Association of Owners of Railroad Securities, 1921–22; Holland vehicular tunnel, 1924–27; and Port of New York Authority since 1927. Doctor Stillwell has served on many of the most important Institute committees, including the executive, code of principles of professional conduct, public policy (now Institute policy) Edison medal, standards, and board of examiners. He also has represented the Institute on the assembly of the American Engineering Council, the Engineering Foundation Board, John Fritz Medal board of award, and the coördination committee of engineering societies. He was a director of the Institute 1896–9, a vice-president 1899–1901, and the president 1909–10. He was vice-president of the American Engineering Council for 4 years, 1930–33 inclusive. He is the author of several important technical papers presented at Institute meetings and published in its TRANSACTIONS. In 1920, he was elected a trustee of Princeton University for life. He was a member of the board of directors of the Chamber of Commerce of the United States, 1921–23. His other memberships in leading engineering and scientific societies include: American Institute of Consulting Engineers, president 1918–19; American Society of Civil Engineers; Institution of Electrical Engineers, Great Britain; National Academy of Sciences; fellow, Royal Society of Arts, Great Britain; American Philosophical Society; and Franklin Institute. He was a member of the National Research Council during the World War. Among the clubs of which he is a member are the Century Association and the Union League Club of New York; Cosmos Club, Washington, D. C.; and Nassau Club, Princeton, N. J. He is a member of Alpha Delta Phi fraternity and of The Holland Society of New York. In 1899, Doctor Stillwell was awarded the Niagara Medal by the president of the Niagara Falls Power Company, Lord Kelvin being the only other electrician awarded this medal. In 1929 the American Society of Civil Engineers conferred upon him a medal "for leadership as chairman of Engineering Foundation in consolidating the research work of the Foundation and the Founder Socieuies."

A. E. ALLEN (A'06, M'13) vice-president, Westinghouse Lamp Company, New York, N.Y., has been elected vice-president of the Westinghouse Electric and Manufacturing Company, New York. Mr. Allen will have charge of the merchandising division which is now established as a separate operation distinct from other divisions of the company. He will have charge of all sales, manufacturing, and engineering activities of this new division. Mr. Allen has been with the Westinghouse company since 1902, first in the engineering division and afterward in the sales department of the electric company, until in 1925 he was made general manager of the lamp company, later becoming its vice-president.

JOHN WEST (A'10, M'28) who for the past 3 years has been manager of the northeastern district of the New England Power Association, with headquarters at Arlington, Mass., has been appointed district manager of a new grouping of the southeastern properties of the association, with headquarters at Fall River, Mass. He has been made president of the Fall River Electric Light Company in addition to having supervision over various utility properties of this group.

J. B. WHITEHEAD (A'00, M'08, F'12, life member, and president) dean, school of engineering, The Johns Hopkins University, Baltimore, Md., has been made an honorary member of the Société Française des Électriciens. On the occasion of the celebration of its fiftieth anniversary last month, the Société awarded this distinction to a prominent electrical engineer in each of the larger European countries, in Japan, and in the United States. Doctor Whitehead received the only award in this country.

F. E. HARRELL (A'26) has been made assistant chief engineer of the Reliance Electric and Engineering Company, Cleveland, Ohio, manufacturers of electric motors. Mr. Harrell joined the Reliance organization upon graduation from Purdue University in 1924. Following sales engineering work in Chicago he returned to Cleveland as special engineer for steel mill motor applications. He has since been chief draftsman and engineer in charge of a-c design.

E. G. FOX (A'12, M'20) has been elected vice-president of the Freyn Engineering Company, a firm of steel mill consulting engineers in Chicago, Ill. Since 1920 Mr. Fox has been power and electrical engineer of this company. As announced in ELECTRICAL ENGINEERING for October 1933, p. 729, he has been identified with the development of the steel industry in the Soviet Union for the past 5 years.

VICTOR SIEGFRIED (A'32) since August 1933 has been instructor in the department of electrical engineering at Worcester Polytechnic Institute, Worcester, Mass. Like his present superior, Prof. T. H. Morgan, Mr. Siegfried came to Worcester from Stanford University, Calif., where he had completed extensive graduate work.

H. D. JAMES (A'98, M'08, F'12) consulting control engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has recently opened an office in Pittsburgh as consulting engineer and industrial control specialist. Mr. James will continue to devote part of his time to the Westinghouse company.

F. M. FARMER (A'02, F'13) vice-president and chief engineer, Electrical Testing Laboratories, New York, N. Y. was elected vice-chairman of the Standards Council of the American Standards Association at its annual meeting held on December 12, 1933.

M. SPECTOR (A'25) formerly Assistant Examiner in the United States Patent Office, and for the last 6 years with Brown, Jackson, Boettcher & Dienner, Chicago, Ill., has opened an office for himself in Chicago, specializing in patents on electrical inventions.

E. A. BALDWIN (A'07), vice-president of the International General Electric Company at Paris, has been elected president of the American Chamber of Commerce in France. The Chamber, with a membership of 700, is 40 years old.

L. W. SMITH (A'22, M'28) formerly assistant electrical engineer with Sargent and Lundy, has recently been appointed district engineer in charge of the newly opened Chicago, Ill., office of the Doble Engineering Company.

B. C. J. WHEATLAKE (A'16) manager, General Electric Company, Salt Lake City, Utah, has been elected a director of the Electrical League of Utah for the present year.

C. A. WOLFROM (A'10) division manager, Utah Power and Light Company, Salt Lake City, has been elected a director of the Electrical League of Utah for the present year.

T. O. MOLONEY (A'12, M'21) president, Moloney Electric Company, St. Louis, Mo., has been elected to the board of directors of the General American Life Insurance Company of that city.

J. C. SMITH (A'03, F'12) president of the Montreal Tramways, and vice-president and general manager of the Shawinigan Water and Power Company, has been elected president of the latter company.

S. W. GREENLAND (A'11, M'17) manager for the receiver of the St. Louis (Mo.) Public Service Company, has been appointed vice-president and general manager of the People's Motor Bus Company.

S. B. WAY (A'03) president of The Milwaukee (Wis.) Electric Railway and Light Company, has been elected a director of the North American Company.

L. H. EGAN (A'08, M'15) president of the Union Electric Light and Power Company, St. Louis, Mo., has been elected a director of the North American Company.

Obituary

JOHN HAROLD MORECROFT (A'06, M'12, F'19) professor of electrical engineering at Columbia University, New York, N. Y., died in California on January 26, 1934, after a brief illness. He was born in 1881 at Barton-under Needwood, Staffordshire, England but emigrated to the United States when a young boy. He attended public school at Syracuse, N. Y., and entered Syracuse University, graduating in 1904 with the degree of E.E. He was foreman in an electrical manufacturing shop from 1904 to 1905. He returned to Syracuse University as assistant and then instructor in both civil and electrical engineering, and

received the degree of B.S. in 1907. In the same year he became instructor in electrical engineering at Pratt Institute, Brooklyn, N. Y., in charge of the laboratories of the department of Applied Electricity. Beginning in 1907, Professor Morecroft began studying under Professor Michael I. Pupin and in 1908–09, he was university scholar in electrical engineering at Columbia University. In 1909 he became instructor in electrical engineering at Columbua University, where his promotion was rapid; in 1923 he was promoted to the rank of professor. During the World War he was employed by the U. S. Navy as a scientist in submarine defense, in which capacity he did much experimental work in this country and later worked in Europe in coöperation with the allied navies. In 1929 Professor Morecroft received the honorary degree of doctor of science from Syracuse University in recognition of many valuable contributions to the art of communication and particularly in the field of radio. He was a past-president of the Institute of Radio Engineers and served on many committees of both the I.R.E. and the A.I.E.E. He was also a member of Tau Beta Pi, Phi Beta Kappa, Sigma Xi, Epsilon Chi, the American Association for the Advancement of Science, and the Society for the Promotion of Engineering Education. Professor Morecroft was best known for his works on radio communication, his text on "Principles of Radio Communication," which first appeared in 1921, and as a third edition in 1933, was recognized the world over as the foremost authority on the subject. He also published books on electronics, electrical circuits, and machinery.

Cyril Francis Mackness (A'08, M'27) senior partner of the firm of Mackness and Shipley, consulting engineers, London, England, died December 17, 1933. He was born in 1872 at Broughty Ferry, Forfarshire, Scotland. He was educated at Heriot-Watt College, Edinburgh, and at Durham College of Science, Newcastle-on-Tyne. During 1898–99 he was in the drawing office of the Sunderland Forge and Engineering Company, Sunderland, England, and during 1899–03 was in the workshop and testing department of Bruce Peebles and Company, electrical engineers. During 1903–04 he was engaged on inspection for Carruthers and Elliot, Edinburgh, and during 1904–14 was manager and chief engineer of the Allgemeine Elek. Gesellschaft of Berlin, in London. During this same period he was, in 1909 and 1910, temporarily manager of the A.E.G. of South Africa, Johannesburg. During 1914 to 1920 he was manager and chief engineer of the electrical department of Vickers, Ltd., and during 1920 to 1924 was manager and chief engineer of the hydroelectric department of this same company. Since 1924 he has been a consulting and inspecting engineer on his own account. His firm carried out many important works for clients in England, the United States, Canada, and various European countries, including Germany, Austria, and Italy. He also undertook extensive work in South Africa and Australia. For the past 28 years he has been a member of the Institution of Electrical Engineers (England).

Carleton Whitney Smith (A'12, M'18) division engineer, Brooklyn Edison Company Brooklyn, N. Y., died January 16, 1934. He was born at Sommerville, Mass., in 1890. He graduated in both electrical and mechanical engineering at Lowell School, Massachusetts Institute of Technology, in 1911. During 1905–07 he was engaged as electrician in various electrical plants and during 1907–08 was assistant to J. S. Stone, consulting electrical engineer. During 1908–11 he was in the electrical engineering department of the Boston (Mass.) Elevated Railway Company. During 1911–13 he was electrical inspector for the Boston Board of Fire Underwriters, and consulting engineer to the Niagara Fire Underwriters Company and other organizations. During 1913–15, he was engaged on mechanical work in the development of manufacturing processes. During 1916–17 he was electrical engineer for the Honolulu Iron Works Company, New York, N. Y., in charge of the electrical engineering department. During 1917–19 he was senior lieutenant in the U. S. Navy. Here he had full responsibility for conducting an organization of 12 subordinate officers, 14 draftsmen, and 150 electricians, engaged on radio work. During 1920–23 he conducted an engineering and contracting business in and near New York City. In 1923 he became assistant engineer in the electric engineering department of the Brooklyn Edison Company. Here he was in charge of a section on station improvements and preliminary study, subsequently becoming division engineer.

James G. Findley (A'28) meter superintendent, and in charge of the service department, Washington Water Power Company, Spokane, Wash., died December 17, 1933. He was born in 1869 at East Pembroke, N. Y. In 1898 he graduated from the Vander Naillen School of Engineering. During 1899–1900 he was municipal burglar alarm operator at San Francisco, Calif., and during 1901–05 he was foreman of the meter department of the San Francisco Gas and Electric Company. During 1905–06 he was engaged on testing meters for the Oakland (Calif.) Gas, Light and Heat Company. In 1906 he transferred to the Washington Water Power Company, continuing as foreman of the meter department until 1920 when he became foreman of the meter and service department of this company.

Charles Wells Nitschke (M'28) Denver plant superintendent for the Mountain States Telephone and Telegraph Company died January 23, 1934. He was born in 1883 in London, Ontario, Can. In 1898 he began a career which led to long and faithful service in the Mountain States Telephone and Telegraph Company at Denver. He started his work as a messenger boy in the Colorado Telephone Company, which company later merged and became a part of the Mountain States Telephone and Telegraph Company. Between the years of 1900 and 1912 he worked throughout the State of Colorado at various occupations from that of an installer, troubleman, lineman, foreman, combination man, and switchboardman, thus gaining an all-around knowledge and experience in his chosen work. In 1912 he was selected as district wire chief, with headquarters at Trinidad, Colo., and a year later was given the position of district plant chief, with headquarters at Grand Junction, Colo., which position he held until 1917, when he was transferred as acting plant superintendent in Denver during the war period. This position he held until 1919. His next advancement was that of District plant chief, with headquarters at Salt Lake City, Utah; a year later he was given the title of Utah plant chief, which position he held until 1921, when he was transferred to Denver as plant superintendent, which position he filled with credit until the time of his death. He was a charter member of the Telephone Pioneers of America.

Membership

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before March 31, 1934, or May 31, 1934, if the applicant resides outside of the United States or Canada.

Abrahams, N., 16 Jefferson St., New Haven, Conn.
Allen, E. C., Am. Tel. & Tel. Co., Denver, Colo.
Anderson, C. A. G., Detroit Edison Co., Mich.
Anderson, E. H., Simplex Elec. Co., Chicago, Ill.
Anderson, H. L., Narragansett Elec. Co., Providence, R. I.
Anderson, L. G., Indianapolis Rys., Ind.
Andis, M. G., Jr., Andis Clipper Co., Racine, Wis.
Angell, E. L., Narragansett Elec. Co., Providence, R. I.
Baker, E. F., Dodge Motor Car Co., Detroit, Mich.
Banta, L. V., McGraw-Hill Pub. Co., N. Y. City.
Barnett, E. E., Warner Bros. Studio, Burbank, Calif.
Bartholow, C. A., Jr., 26 W. Prentiss St., Iowa City, Iowa.
Bastedo, G. R., 102–36 86 Rd., Richmond Hill N. Y.
Battle, J. H., Memphis Pwr. & Lt. Co., Tenn.
Beck, G. R., C.W.A. Surveying, Mercersburg, Pa.
Belcher, A. B., Westinghouse Elec. & Mfg. Co., Springfield, Mass.
Bell, W. M., Box 994, Charlotte, N. C.
Bentley, A. T., British Col. Elec. Ry. Co., Ltd., Vancouver, B. C., Can.
Beyette, C. K., Texas Elec. Serv. Co., Fort Worth, Texas.
Bishop, LeR. D., C.W.A., Carlisle Barracks, Pa.
Black, F. S., Nantahala Pwr. & Lt. Co., Bryson City, N. C.
Blackburn, R. K., 600 Clinton Ave., Albany, N. Y.
Blickenstaff, I. C., The Chesapeake & Potomac Tel. Co. of Va., Richmond.
Block, I. D., Buffalo Niagara & Eastern Pwr. Corp., Buffalo, N. Y.
Blount, C. C., 509½ E. Walnut St., Cushing, Okla.
Boesch, A. J., Western Elec. Co., Phila., Pa.
Boughton, W. M., Western Union Tel. Co., Memphis, Tenn.
Bressler, H. E., N. J. Pwr. & Lt. Co., Dover.
Bronwell, A. B., Commonwealth Edison Co., Chicago, Ill.
Bruhn, R. A., Electro-Dynamic Co., Bayonne, N. J.
Bryan, C. B., Ford Instr. Co., Inc., Long Island City, N. Y.
Burnett, J. H., Pub. Serv. Elec. & Gas Co., Newark, N. J.
Burns, J. F., 200 Lee Highway, Clarendon, Va.
Burr, R. E., 247 Elmwood Ave., Elmira Heights, N. Y.
Butler, A. G., Am. Concrete & Steel Pipe Co., Oakland, Calif.
Caboon, E. F., 24 Milton Ave., Dorchester, Mass.
Campaigne, R. N., 78 Plymouth St., Montclair, N. J.

Capwell, R. I., 474 Fairview Ave., Anthony, R. I.
Carlson, R. C., Lock Box 38, Ludlow, Pa.
Carmody, J. F., Intl. Business Machines Corp., Endicott, N. Y.
Carns, W. L., 5112 Whitby Ave., Phila., Pa.
Carson, J., United Elec. Lt. Co., Springfield, Mass.
Carson, J. J., 402 Somerville Ave., Phila., Pa.
Cevela, F. C., 348 E. York Ave., West Chicago, Ill.
Clagett, J. L., Cincinnati & Suburban Bell Telephone Co., Norwood, Ohio.
Clagett, W. H., Jr., 124 Kellogg Ave., Kellogg, Idaho.
Clark, K. H., James Clark, Jr., Elec. Co., Louisville, Ky.
Clark, R. U., Magnavox Co., Ft. Wayne, Ind.
Coffman, E. S. (Member) Federal Pwr. Commission, Washington, D. C.
Colenda, S., C.W.A. Projects, Union City, N. J.
Collin, A. J., Montmagny Furniture Mfg. Co., Ltd., Montmagny, P. Q., Can.
Colpitts, A. L., Radisson, Wis.
Comer, W. F., Gen. Elec. Co., Bridgeport, Conn.
Coombs, W. C., Harrington, Wash.
Corrigan, D. J., Sunrise, Wyo.
Cree, J. G., Civil Works Project, Chambersburg, Pa.
Creim, C., 1000 Palms Camp, Indio, Calif.
Crick, R. W., 802 Grace Ave., Ft. Wayne, Ind.
Currie, A. A., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Davies, P. T., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Day, E. C., N. Y. Edison Co., N. Y. City.
Deise, L. F., 327 St. Paul Place, Baltimore, Md.
Detmers, F. H., 14542 Van Owen St., Van Nuys, Calif.
DiLello, P. J., 31 Hampton St., Albany, N. Y.
Dodge, C. M., Monterrey Ry. Lt. & Pwr. Co., Monterey, Mexico.
Dunlap, G. W., P. O. Box 36, Sonora, Calif.
Dunnington, W., Belle Alkali Co., Belle, W. Va.
Eddy, K. L., 188 Church St., Saratoga Springs, N. Y.
Ekstrom, I. R., Commonwealth Edison Co., Chicago, Ill.
Emanuel, V., 2330 Hillcrest Dr., Los Angeles, Calif.
Erikson, R., 1410 Farragut Ave., Chicago, Ill.
Evans, W. T., Texas Pwr. & Lt. Co., Trinidad.
Filion, O., 1227 N. Cass St., Milwaukee, Wis.
Fizzell, J. A., Standard Elec. Inst. Lab., Kansas City, Mo.
Foster, J. I., Dept. of Utilities, Fremont, Neb.
Frazier, H. M., Pub. Works Administration, Fort Humphreys, Va.
Fredrickson, R. S., Deep Rock Oil Corp., Burlington, Wis.
Friebele, E. J., Kenyon Transformer Co., Inc., N. Y. City.
Fry, H. H., Assoc. Gas & Elec. Co., W. Reading, Pa.
Funk, E. J., Jr., C. M. Kemp Mfg. Co., Baltimore, Md.
Galiulo, F. L., N. Y. Edison Co., Bronx, N. Y.
Gams, F. J., North Serven St., Pearl, River, N. Y.
Gardner, F. V., U. S. Coast & Geodetic Survey, Ukiah, Calif.
Garrett, T. J., Jr., Harriet Cotton Mills, Henderson, N. C.
Gegenheimer, W. C., Westinghouse Lamp Co., Bloomfield, N. J.
Gess, M. M., Box 264, Dolton, Ill.
Gnuse, H. H., Jr., Univ. of Tenn., Knoxville.
Graves, D. E., C.W.A., at Univ. of Wis., Madison.
Green, H. H., Jr., 1568 So. Fourth East, Salt Lake City, Utah.
Griessel, O. T., Odessa, Mo.
Guettler, R. O., Globe Union Mfg. Co., Milwaukee, Wis.
Hamm, J. E., Barboursville, Orange Co., Va.
Hanwick, T. J., Ford Instr. Co., Long Island City, N. Y.
Harper, J. D., Aluminum Co., of Am., Tapoco, N. C.
Hartman, W. E., Republic Steel Corp., Canton, Ohio.
Haworth, R. A., 114 E. Main, Madison, Wis.
Haynes, M. L., Balfour Tech. School, Regina, Sask., Can.
Hedley, J. B., West Kootenay Pwr. & Lt. Co., Ltd., South Slocan, B. C., Can.
Hegeman, G. D., Jr., Glen Head, L. I., N. Y.
Hegy, L., 70 B. So. 8th St., San Jose, Calif.
Heibel, J. D., 3302 Parade St., Erie, Pa.
Heinisch, G. H., Jr., 21 Winthrop St., New Britain, Conn.
Hejduk, A. A., Fenn Evening Engg. Col., Cleveland, Ohio.
Herron, R. C., 901 40th St. Pl., Des Moines, Iowa.
Hess, E. F., Bklyn. Edison Co., Inc., Bklyn., N. Y.
Higgins, C. E., Box 45, Reader, W. Va.
Himes, C. F., Box 824, Hominy, Okla.
Hines, A. R., Gen. Elec. Co., Roanoke, Va.
Holmquist, R. H., Madison Gas & Elec. Co., Wis.
Huffman, E. W., Cunningham, Kans.
Hunt, R. W., Intl. Narrow Fabric Co., Keene, N. H.
Hunter, J. E., 372 Montford Ave., Asheville, N. C.
Ivaska, J. P., Mass. Highway Accident Survey, Boston, Mass.
James, L. I., 21 Emma St., Greer, S. C.
Johnson, M. D., Cabell Elec. Co., Jackson, Miss.
Johnson, W. B., U. S. Bureau of Reclamation, Denver, Colo.
Jones, M. P., Pollock Paper & Box Co., Dallas, Texas.
Karr, L. A., 733 Park Ave., E. Orange, N. J.
Kehoe, L. F., 860 15th St., La Salle, Ill.
Keller, E. H., 667 Jefferson Place, Bronx, N. Y.
Kirkpatrick, A. E., U. S. Bureau of Public Rds., Grangeville, Idaho.
Kisner, A. G., Gen. Elec. Co., Phila., Pa.
Knight, E. W., Stillwater Worsted Mills, Harrisville, R. I.
Kuehlthau, J. L., 384 Division St., West Bend, Wis.
Kunz, M. C., Weston Elec. Instr. Corp., Newark, N. J.
Kupka, A. J., 1115 So. 7th St., Minneapolis, Minn.
Kurman, H., 580 McAllister St., San Francisco, Calif.
Kyne, T., 107 Summit St., Norwich, Conn.
Lang, L. M., 47 Algonquin St., Providence, R. I.
Layton, J. W., Route 1, Osborne, Ohio.
Lefever, H. L., Armstrong Cork Co., Lancaster, Pa.
Leisure, E. C., 1017 Fairfield Ave., Ft. Wayne, Ind.
Lewis, C. H., Sesser, Ill.
Livingstone, J. T., Canadian Natl. Telegraphs, Winnipeg, Manitoba, Can.
Lomas, G. E., U. S. Coast & Geodetic Survey, Washington, D. C.
Lorenzen, H., Western Sugar Refining Co., San Francisco, Calif.
Lowe, B. E., Continental Oil Co., Ponca City, Okla.
Lyshoj, G. J., Inter State Pwr Co., Clinton, Iowa.
MacKey, C. M., Westinghouse Elec. Supply Co., Okla. City, Okla.
Magee, L., C.W.A. Project, Lubbock, Texas.
Magruder, S. H., 1517 Rhode Island St., Lawrence, Kans.
Martin, R. C., Crown Willamette Paper Co., Camas, Wash.
Matthews, W. J., Blackstone Valley Gas & Elec. Co., Pawtucket, R. I.
McBride, R. L., Canadian & Gen. Finance Co., Toronto, Ont., Can.
McCaa, J. R., 1130 Elm Ave., Lancaster, Pa.
McCann, H. J., N. A. Timmins Corp., Porcher Island, B. C., Can.
McKendry, V. J., Chrysler Corp., Detroit, Mich.
McLoughlin, T. F., 48 North Ave., Meriden, Conn.
McNabb, T., Wheeling Tile Co., Wheeling, W. Va.
McQueary, F. K., Texas-Louisiana Pwr. Co., Ft. Worth, Texas.
Meyer, F. C., Okonite-Callender Cable Co., Inc., Paterson, N. J.
Moody, H. H., 111 State Drive, Norman, Okla.
Moore, M. M., Clay Center, Neb.
Moore, R. R., 115 East Oak Ave., El Segundo, Calif.
Morgan, W. A., Metropolitan Water Dist. of So. Calif., Banning, Calif.
Morris, L. H., Jr., Richmond Dept. of Pub. Works, Va.
Munch, J. A., 247 River Ave., Lakewood, N. J.
Myers, A. F., Intl. Boundary Comm., Blaine, Wash.
Nelson, K. G., Michigan Bell Tel. Co., Houghton, Mich.
Newlon, A. E., U. S. Coast & Geodetic Survey, Washington, D. C.
Nixon, F. G., Box 118, West Summerland, B. C., Can.
Nord, G. L., 216 "J" St., La Porte, Indiana.
Oleinikoff, S. J., Solar Mfg. Co., N. Y. City.
Ott, W. J., 3212 Decatur Ave., Bronx, N. Y.
Page, G. I., Southwestern Lt. & Pwr. Co., Lawton, Okla.
Page, H. H., 87 Gym, Rensselaer Poly. Inst., Troy, N. Y.
Painter, E. O., Duquesne Lt. Co., West Bridgewater, Pa.
Panzarella, M. A., 28 W. Main St., Falconer, N. Y.
Pearson, J. B., Oil Well Supply Co., Bradford, Pa.
Perkins, H. A., Jr., Fleetwings, Inc., Garden City, L. I., N. Y.
Perleberg, G. C., South St., Fort Lee, N. J.
Peterson, D. A., Radio Station KRLD, Dallas, Texas.
Pharo, E. W., Jr., High Pressure Pump Corp., Wilkes-Barre, Pa.
Philippi, C. L., Phila. Stor. Bat. Co., Pa.
Piper, W. A., Jr., C.W.A., Soil Erosion Project, Wauzeka, Wis.
Pitts, W. L., Philco Radio & Television Co., Phila., Pa.
Ponzer, K. L., North Carolina State Highway Comm., Elizabethtown, N. C.
Pratt, D., Radio Station WIBW, Topeka, Kansas.
Pretty, H. R., Okla. Gas & Elec. Co., Shawnee.
Price, W. K., 20 Washington Place, Newark, N. J.
Prieskorn, R. E., 710 Central Ave., Fort Dodge, Iowa.
Pringle, E. B., 53 West 150 St., Harvey, Ill.
Quick, C. E., Detroit Edison Co., Monroe, Mich.
Rader, L. T., Canadian Elec. Mfg. Co., Vancouver, B. C., Can.
Renton, W. B., 1137 Howard Ave., Utica, N. Y.
Reuss, W. H., Pub. Serv. Comm. of Wis., Madison.
Reynolds, J. H., Jr., Westinghouse Elec. Supply Co., Jacksonville, Fla.
Richardson, W., 1864 E. 71 St., Cleveland, Ohio.
Rigling, V. F., 137 Market St., New Cumberland, Pa.
Riner, W. B., U. S. Engrs. Depot, Sayler Park, Cincinnati, Ohio.
Roberts, F. A., 501 S. Main St., Monticello, Ind.
Roberts, G. W., Albany, Wis.
Rogers, J. V., R. M. D., 3, Glanford Ave., Victoria, B. C., Can.
Rohkohl, G. W., 7237 S. Oakley Ave., Chicago, Ill.
Rosenzweig, J., 335 Second Ave., Kingston, N. Y.
Ross, P. M., Frigidaire Corp., Dayton, Ohio.
Rotroff, J., Logansport Machine Co., Logansport, Ind.
Roy, W. H., Pacific Can Co., San Francisco, Calif.
Rudd, W. C., N. Y. Edison Co., Bronx, N. Y.
Sanchez, J. R., Sria de Comunicaciones Mexico, D. F., Mexico.
Sander, M., 2647 E. Clearfield St., Phila., Pa.
Sandretto, E. D., Clough-Brengle Co., Chicago, Ill.
Schmidt, G. F., 731 State St., Madison, Wis.
Schneider, H. C., Nestle's Milk Products Co., Marysville, Ohio.
Schneider, V. W., 1423 5th Ave., So. Fargo, N. D.
Schroeder, H. E., 206 Hillside Ave., Glen Ridge, N. J.
Schwehr, L. J., Sanborn, N. D.
Seigfreid, C. R., W. G. Shelton Co., St. Louis, Mo.
Sfat, P., 829 St. Clair Rd., Grosse Pointe, Mich.
Shaad, P., Gen. Elec. Co., Schenectady, N. Y.
Shallcross, G. P., 4713 Pensacola Ave., Chicago, Ill.
Shields, C. I., 704 Remington St., Ft. Collins, Colo.
Skaff, P. S., E. I. du Pont de Nemours Corp., Charleston, W. Va.
Slay, W. B., 215 W. Georgetown St., Crystal Springs, Miss.
Sorenson, L. M., U. S. Coast & Geodetic Survey, Beloit, Wis.
Stelzer, W. A., 108 E. Jefferson St., Brooksville, Fla.
Stevens, T. E., Budd Mfg. Co., Phila., Pa.
Stringham, L. K., Lincoln Elec. Co., Cleveland, Ohio.
Sugden, A. C., 1418 Union St., Schenectady, N. Y.
Sullivan, S. A., Jerome, Idaho.
Sweetman, J. G., N. Y. Edison Co., N. Y. City.
Tamm, E. S., 1413 Carr Ave., Memphis, Tenn.
Taylor, R. L., U. S. Dept. of Commerce, Cheyenne, Wyo.
Thomas, G. J., Paramount Studios, Hollywood, Calif.
Thomas, S. O., 413 S. Market St., Troy, Ohio.
Tolentino, J. G., 3721 N. Cicero Ave., Chicago, Ill.
Trevor, J. B., Jr., 11 East 91 St., N. Y. City.
Trimble, R. M., 618 Herndon Ave., Shreveport, La.
Trussler, L. C., Am. Tel. & Tel. Co., Denver, Colo.
Tyler, G. F., Phila. Elec. Co., Pa.
Uffelman, W. R., Goodyear Tire & Rubber Co., Akron, Ohio.
Ulrich, G. H., Jr., Armstrong Cork Co., Lancaster, Pa.
Underhill, D. F., Gen. Elec. Co., Minneapolis, Minn.
Unger, S., Eagle Elec. Mfg. Co., Bklyn., N. Y.
Veno, M. E., 12 Second St., Attleboro, Mass.
Wages, R. W., U. S. Coast & Geodetic Survey, Auburn, Ala.
Walter, J. S., Stanco Distributors, Inc., N. Y. City.
Walton, J. H., 115 Ogden Ave., Swarthmore, Pa.
Ward, R. DeW., Am. Model R. R. Co., New Rochelle, N. Y.
Wasson, L. C., Tucker Duck & Rubber Co., Ft. Smith, Ark.
Watkins, R. V., 1005 S. 22 St., Columbus, Ohio.
Wesner, C. T., Standard Oil Co., Inc., Sugar Creek, Mo.
Westby, S. B., Commonwealth Edison Co., Chicago, Ill.
Wight, O. M., Gen. Elec. Co., Schenectady, N. Y.
Wilie, C. L., Jr., U. S. Coast & Geodetic Survey, Falfurrias, Texas.
Wilson, E. C., 504 E. Church St., Marion, Ohio.
Wiltshire, G. W., D. L. & W. R. R., Scranton, Pa.
Wing, A. H., Jr., Col. of the City of N. Y., N. Y. City.
Winn, W. P., Metropolitan Water Dist. of So. Calif., Los Angeles, Calif.
Wisleder, D. E., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Wood, J. P., Cornell Univ., Ithaca, N. Y.
Woodzell, S. R., 21 Fairfax Pl., Clarendon, Va.
Woolman, S., 112 First St., Troy, N. Y.
Zane, R. B., The Okonite Co., Passaic, N. J.
Zeffren, H. E., Wagner Elec. Corp., St. Louis, Mo.
Zillafro, J. A., Messer Oil Corp., Olean, N. Y.

256 Domestic

Foreign

Appasamy, C. S., 51 Barton St., Kensington W.14, London, Eng.
Arias, J. L., Porto Rico Railway Lt. & Pwr. Co., Comerio, P. R.
Cage, A. G., Jr., South Porto Rico Sugar Co., of P. R., Ensenada, P. R.
Chawla, S. H. (Member), Sugar Factory, Mansurpur Dist., Muzarernagar, India.
Engineer, K. P., Municipal Pwr. House Sukkur, Sind, India.
Patel, P. V., Sunav, Via Anand, India.
Samson, I. H., 1443 Webb Rd., Cincinnatus Town, Karachi, India.
Stanbridge, C. H. (Member), P. O. Box 1230, Cape Town, South Africa.
Visvanathan, M. S., ASEA, Vasteras, Sweden.
Wang, K. S., Chekiang Univ., Hangchow, Chekiang Province, China.
Yakovlev, V. M., Moscow Elec. Pwr. Lt. Co., Moscow, U. S. S. R.

11 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the address as it now appears on the Institute record. Any member knowing of corrections to these

addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Darcy, Harris B., 305 M. & M. Bldg., Houston, Texas.
Dean, George H., Corrie, Old Shoreham Road, Shoreham-by-Sea, Eng.
Gentilini, Celso, 1512 Wood St., Wilkinsburg, Pa.
Griffith, Geo. M., R. no. 1, Tucker, Ga.
How, John H., 42 Wai Oi Road East, Canton, China.
Lober, Charles, K. C. P. & L. Co., 1330 Baltimore Ave., Kansas City, Mo.
Mathisen, Karsten V., 912 Noyes St., Evanston, Ill.
Panton, H. D., Phoenix Utility Co., c/o Kansas Gas & Elec. Co., Wichita, Kans.
Shifrin, Leonard I., c/o Tanenbaum, 12 Pinehurst Ave., New York City.
Soskin, Samuel B., 1225 S. Calif. Ave., Chicago, Ill.
Sparks, Losey D., 1507 Sherwin Ave., Chicago, Ill.
Talbot, H. L., 55 Pine Ave. E., Montreal, Que., Can.
Whittemore, J. D., 126 State St., Albany, N. Y.

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, during January are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface or text of the book in question.

INVENTIONS, PATENTS and TRADE-MARKS, Their Protection and Promotion. By M. Wright. 2 ed. N. Y. and Lond., McGraw-Hill Book Co., 1933. 310 p., 8 x 6 in., cloth, $2.50. Tells how to choose a patent attorney, what patent-office procedure is, and how to estimate the value of a patent. Methods of disposing of patents are described, the relations of inventor and employer are discussed, and various traps set for patentees are noted.

LEITFADEN der ELEKTROTECHNIK, Band 1, Teil 1 and 2. Grundlagen des Gleich- und Wechselstromes. By F. Moeller and G. Bolz. Leipzig and Berlin, B. G. Teubner, 1933. 94 p., illus., 10 x 6 in., cloth, 9.60 rm. An introductory presentation of the fundamentals of electrical engineering, intended for students of other branches of engineering as well as for those who intend to specialize in this field. Graphic methods are used extensively and calculus is seldom used. Three-color diagrams are employed for greater clarity.

ROHRHYDRAULIK, Allgemeine Grundlagen, Forschung, Praktische Berechnung und Ausführung von Rohrleitungen. By H. Richter. Berlin, Julius Springer, 1934. 256 p., illus., 10 x 6 in., cloth, 22.50 rm. This monograph aims to present a practical summary of all the available information upon the flow of fluids in pipes which is of practical usefulness.

THÉORIE de la TRANSMISSION TÉLÉPHONIQUE. By M. G. Valensi. Paris, Librairie de l'Enseignement Technique, Léon Eyrolles, 1933. 626 p., illus., 10 x 7 in., paper, 80 frs. This textbook on the theory of telephonic transmission presents the course given at the Ecole Professionnelle Supérieure des Postes et Télégraphes at Paris. It supplies a summary of the subject, using only simple mathematics. The review covers both wire and radio circuits for transmitting music and for television.

TRADE ASSOCIATIONS, Management Policies, Organization, Personnel, Services. By W. J. Donald. N. Y. and Lond., McGraw-Hill Book Co., 1933. 437 p., 9 x 6 in., cloth, $4.00. The organization, management, and operation of trade associations are discussed in a practical way by an experienced executive. The business man is told how an association may be organized, what it can do, and what it may achieve; and the executive of an association is advised about his duties and their execution.

Der WÄRME- und STOFFAUSTAUSCH dargestellt im Mollierschen Zustandsdiagramm für Zweistoffgemische. By A. Busemann. Berlin, Julius Springer, 1933. 75 p., illus., 10 x 6 in., paper, 6 rm. By introducing a new concept, "exchange flow," which includes radiation, diffusion, and convection, the author shows how the problems of heat exchange may be solved more easily and exactly than heretofore. The new factor may be introduced into the Mollier phase diagram for mixtures of 2 components, and is accurate for both laminar and turbulent flow.

JAHRESBERICHT 1932 DER ABTEILUNG für ELEKTROTECHNIK und FUNKWESEN der DVL. (Sonderdruck aus dem Jahrbuch 1932 der Deutschen Versuchsanstalt für Luftfahrt, E. V., Berlin-Adlershof). By H. Fassbender. Munich and Berlin, R. Oldenbourg, 1933. 96 p., illus., 12x8 in., paper, 6.75 rm. The papers presented at the annual meeting for 1932 of the electrical and radio section of the German Aviation Research Laboratory are here reprinted from the 1932 yearbook of the laboratory. Eleven papers are given, discussing various problems connected with airplane radio equipment, engine ignition, etc.

An der WIEGE des ELEKTRISCHEN TELEGRAPHEN. (Deutsches Museum Abhandlungen und Berichte, Jg. 5, Heft 5). By E. Geyerabend. Berlin, VDI-Verlag, 1933. 143–174 p., illus., 8x6 in., paper, 90 rm. This essay discusses briefly early attempts at electric telegraphy, beginning with Soemmering's experiments and ending with Morse's invention. The account is illustrated from early apparatus preserved in the Deutsches Museum and is issued to commemorate the centenary of the Gauss-Weber needle telegraph, erected at Göttingen in 1833.

COST AND PRODUCTION HANDBOOK. Edited by L. P. Alford and a board of 80 authorities. N.Y., The Ronald Press Co., 1933. 1600 p., illus., 5x7½ in., cloth, $7.50. Designed to give practical working information on cost and production problems to all engaged in manufacturing, whether in shop or office position, coördinated and organized to apply under present conditions; covers all the more important activities of industrial operation. (A.I.E.E.)

A T M—Archiv für technisches Messen. Nos. 27–30, Sept.–Dec. 1933. Munich and Berlin, R. Oldenbourg, p. 125–170, illus., 12x8 in., paper, 1.50 rm. each no. This work, which appears serially, is intended to form an encyclopedia of measuring instruments and methods used in engineering. Brief articles by specialists are included, and new instruments are described by the manufacturers. The material is so arranged that it may be placed in loose-leaf binders.

Book of A.S.T.M. TENTATIVE STANDARDS, 1933. Phila., Am. Soc. for Testing Materials, 1933. 1136 p., illus., 9x6 in., paper, $7.00; cloth, $8.00. This annual publication contains all the specifications, methods of test and definitions of terms which the Society has approved tentatively, but has not adopted as standards. They thus represent the latest ideas upon subjects not yet standardized. 223 tentative standards are given, of which 47 are new and 41 newly revised.

CHEMICAL PATENTS INDEX, 1915–1924. Vol. 4, Subject Index, M-R. By E. C. Worden. N. Y., Chem. Cat. Co., 1934. 1132 p., 10x7 in., cloth, $25.00. This index covers the patents issued by the U. S. during 1915–24 which relate to chemical technology. The present volume covers the letters M to R. Over 6,000 references to "oil" are given; nearly 5,000 to "paper," and almost 3,000 to "nickel."

COURANTS de COURT-CIRCUIT. (Mises au Point Électrotechniques.) By J. Fallou. Paris, J. B. Baillière et Fils, 1933. 180 p., illus., 7x5 in., cloth, 27 frs. This brief monograph is intended as an introduction to the study of short-circuit phenomena in transmission systems. The calculation of short-circuit currents, the impedances of the various elements of a transmission system, and methods for the control of short-circuits in high-voltage lines are discussed concisely.

COURANTS de FOUCAULT. (Mises au Point Électrotechniques.) By P. Bunet. Paris, J. B. Baillière et Fils, 1933. 180 p., illus., 7x5 in., lea., 25 frs. This work, sponsored by the French Society of Electricians, affords a convenient summary of the widely scattered literature upon eddy currents. The various phenomena are discussed in a uniform manner, with special attention to practical details which will assist in the calculation of losses in circuits. Numerous numerical applications are given.

DEUTSCH-ENGLISCHES FACHWÖRTERBUCH der METALLURGIE (Eisen- und Metallhüttenkunde). Pt. 1. Deutsch-Englisch. Edit. by H. Freeman. Leipzig, Otto Spamer Verlag, 1933. 327 p., 7x5 in., lea., 25 rm. A dictionary for the reader of German metallurgical writings. Over 33,000 terms are included, with accurate English equivalents. The vocabulary includes terms in mechanical and electrical engineering, chemistry and physics, as well as metallurgy. The book is small enough for the pocket, and the print is legible, though small.

DIFFERENTIAL EQUATIONS. By L. R. Ford. N. Y. and Lond., McGraw-Hill Book Co., 1933. 263 p., illus., 9x6 in., cloth, $2.50. A course in the subject which can be covered in a year by a class of ordinary ability. In the introductory part of the presentation the geometrical and intuitive aspects of the subject are emphasized. Succeeding this the rigorous method of approach is presented. A feature is a chapter on interpolation and numerical integration.

(The) DISCOVERY of the ELEMENTS. Collected Reprints of a Series of Articles Published in the Jl. of Chem. Education. By M. E. Weeks. Easton, Pa., Jl. of Chem. Education (Mack Printing Co.), 1933. 363 p., illus., 9x6 in., cloth, $2.00. A narrative of the discovery of the chemical elements. Bibliographies are included in each chapter and there is a useful chronological table. A valuable history of the subject.

DYNAMICS OF EARTHQUAKE RESISTANT STRUCTURES. By J. J. Creskoff. N. Y. and Lond., McGraw-Hill Book Co., 1934. 127 p., illus., 9x6 in., cloth, $2.50. The problem of designing structures that are resistant to earthquakes is primarily a dynamic rather than a static one. In this treatise dynamic methods are applied and formulas developed which make possible the design of aseismic buildings at costs but slightly above those of ordinary structures.

ELECTRIC METERS. By R. R. Ranson. Chicago, Am. Tech. Soc., 1934. illus., 9x6 in., cloth, $2.00. An elementary text intended to give the reader a working knowledge of electric meters. The principles underlying the design of the various types, and the way in which each operates are explained. The uses are described and instruction given in caring for them.

ELEMENTS of HYDRAULIC POWER GENERATION. By A. M. Greene, Jr. N. Y., John Wiley & Sons, 1934. 58 p., illus., 9x6 in., paper, $1.00. A brief exposition of the apparatus used to develop hydraulic power. The uses, limitations, and names of the modern forms of hydraulic machinery are presented.

GREAT BRITAIN. Dept. of Scientific and Industrial Research. FOOD INVESTIGATION Special Report No. 8. MEASUREMENT of HUMIDITY in CLOSED SPACES. Lond., His Majesty's Stationery Office, 1933. 70 p., illus., 10x6 in., paper, 1s 6d. (Can be obtained from British Library of Information, New York, $.50.) Devoted largely to experiments with hygrometers, undertaken primarily to ascertain their reliability as measures of humidity. The existing types are discussed in detail. A brief discussion of methods of air-conditioning is included.

GREAT BRITAIN. Dept. of Scientific and Industrial Research. REPORT of the FUEL RESEARCH BOARD for the Year ended March 31, 1933 with Report of the Director of Fuel Research. Lond., His Majesty's Stationery Office, 1933. 140 p., illus., 10x6 in., paper, 2s 6d. (Obtainable from British Library of Information, N. Y., $.77.) Among the lines along which progress is reported are the cleaning of fine coal, carbonization and gasification processes, hydrogenation of tar and coal, firing of pulverized fuel, and various minor problems of fuel utilization.

(The) GREAT LAKES—ST. LAWRENCE DEEP WATERWAY to the SEA. By T. Ireland. N. Y. and Lond., G. P. Putnam's Sons, 1934. 223 p., illus., 8x5 in., cloth, $2.00. The effect of the waterway upon shipping rates and upon railways, its cost, the arguments for and against the project, its probable use and other questions are discussed in this volume. The author is an ardent advocate of the plan.

Engineering Societies Library

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MAINTAINED as a public reference library of engineering and the allied sciences, this library is a cooperative activity of the national societies of civil, electrical, mechanical, and mining engineers.

Resources of the library are available also to those unable to visit it in person. Lists of references, copies or translation of articles, and similar assistance may be obtained upon written application, subject only to charges sufficient to cover the cost of the work required.

A collection of modern technical books is available to any member residing in North America at a rental rate of five cents per day per volume, plus transportation charges.

Many other services are obtainable and an inquiry to the director of the library will bring information concerning them.

Industrial Notes

Allis-Chalmers District Office Moved.—The Buffalo district office of Allis-Chalmers Mfg. Co. was moved to the Liberty Bank Building on February 24. A. D. Brown is district manager in charge.

Simplex Wire Co. Elects Officers.—At its annual meeting on February 19 the Simplex Wire and Cable Co. elected the following officers: president and treasurer, Henry A. Morss; vice-presidents, Philip R. Morss, Everett Morss, Jr., Charles R. Boggs; assistant treasurer, J. Arthur Gibson. Mr. Boggs was also elected a director.

Penn. R.R. Electrification Resumed.—Actual construction on Pennsylvania Railroad's $77,000,000 electrification and equipment project, financed by the Public Works Administration, is now under way. Present plans call for the employment of steadily increasing forces on the project, reaching a total of more than 6,000 men in the entire territory between New York, Trenton, Philadelphia, Baltimore, and Washington when the work gathers headway. In addition to the erection of steel supports and the catenary wire system over 108 miles of route between Wilmington and Washington, in seven great freight yards and on several branch lines, comprising 646 miles of track, the comprehensive project involves reconstruction of bridges, the rearrangement and relocation of signals and telegraph and telephone lines, lowering of station tracks and platforms, the rearrangement of certain trackage and the construction of 16 new substations and additions to 18 existing substations. Over a year will be required to complete the work, which will make possible the inauguration by the Pennsylvania in 1935 of through electrified service, both passenger and freight, between New York, Philadelphia, and Washington. The cost of this portion of the railroad's improvement program, financed by the Government, is $45,000,000.

Electric Erasing Machine.—A new electric erasing machine, combining unusual lightness and compactness with high efficiency and durability, is announced by the Charles Bruning Company, Inc., New York and Chicago. The new device which is being marketed at a low price, is designed to be held in the fingers like a pencil, enabling the operator to maintain accurate finger control when erasing pen or pencil lines from tracings or drawings. It is operated by a small motor. A complete assortment of pen and pencil erasers accompanies the equipment.

A New Oil Insulation.—A new type of insulating material, known as Harvel Oil Stop, is announced by the Irvington Varnish & Insulator Co. of Irvington, N. J. It is a viscous, non-drying oil which is applied in the form of a liquid and then "sets" in location, even in the absence of air, to form a firm rubber-like structure which is not affected by oil or strong solutions of either acid or alkali, and is waterproof and weatherproof. Heat will not soften it but only hastens its reaction to a rubber-like solid. Oil Stop does not contain any solvents and adheres to rubber, varnished cambric, oil impregnated paper, and copper. These qualities, in addition to its excellent electrical properties, are said to make it particularly suitable for use in all types of cable splices and cable terminals and particularly for splicing oil impregnated paper insulated cables to rubber insulated cables.

G-E Impulse Circuit Breaker.—A new high voltage, large capacity oil circuit breaker, containing many unusual and new features, has been announced by the General Electric Co. Radically different in design, each single-pole unit of the new breaker is shaped like a cross in contrast to the tanklike construction of conventional equipment. Higher breaking speeds with short arcing times and the use of very little oil are among the distinct advantages offered by the new equipment. Only 96 gallons of oil per pole are required by a breaker with an interrupting rating of 1,500,000 kva at 138 kv compared with approximately 1700 gallons per pole for a conventional breaker of an equivalent interrupting rating. Horizontal containers, not much larger than conventional bushings, enclose the interrupting mechanisms. These containers are mounted on vertical central supports which, in addition to serving in an insulating capacity, also house current transformers when such equipment is required. The operating mechanism is located in the base of each single-pole unit and an insulated operating rod passes up through the central support to the container. The interrupting elements consist of several sets of contacts in a line and the inside of each container is so arranged that oil, driven by a piston, is positively directed across the arc path of each of the several arc breaks per pole during circuit interruption.

Trade Literature

Magnet Wire.—Catalog, 32 pp. Describes various types of magnet wire; includes comprehensive tables. General Cable Corp., 420 Lexington Ave., New York.

Ventilating Fans.—Bulletin, 30 pp., "Sensible Ventilation." Illustrates a wide variety of propeller fans and numerous, typical installations. Ilg Electric Ventilating Co., 2850 N. Crawford Ave., Chicago.

Relays.—Catalog. The regular standard line of Dunco relays, and many other types of units are described, as well as special thermostats, electric counters, etc. Struthers Dunn, Inc., 139 N. Juniper St., Philadelphia.

Texrope Drive Sheaves.—Bulletin 2134-A, 4 pp., gives engineering data, such as sheave diameters, number of grooves, bores and other dimensions on Texsteel sheaves for Texrope drives. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Fire Extinguishing Apparatus.—Bulletin, 12 pp. Describes Du Gas dry chemical fire extinguishing apparatus, appliances and systems, applicable to electrical machinery in central stations and substations. Garrison Engineering Corp., 307 Fifth Ave., New York.

Circuit Breakers.—Catalog 33–200, 36 pp. Describes a complete line of small oil circuit breakers, up to 50,000 kva, including tables giving the proper type of breaker for any indoor, outdoor, or subway requirement. Westinghouse Electric & Mfg. Co., East Pittsburgh.

Self-Tapping Screws and Fastenings.—Catalog 4, 34 pp. Describes labor-saving fastening devices such as self-tapping and drive screws for making fastenings to sheet metal, castings, Bakelite, slate, ebony, asbestos, etc. Applications in electrical and allied manufacture are outlined. Parker-Kalon Corp., 200 Varick St., New York.

Lathes.—Catalog 94, 72 pp. Describes a complete line of lathes and attachments adaptable for manufacturing production, machine, maintenance, and electrical shops. The catalog illustrates 96 sizes and types of lathes, all of the back-geared, screw cutting type, with prices. South Bend Lathe Works, South Bend, Ind.

Starting Switch.—Bulletin 709, 4 pp. Describes a new, across-the-line, a-c starting switch available with start and stop push button for general industrial and machine tool applications; with either 2 or 3 wire pilot controls, such as a float switch, thermostat, a separate push button, etc.; providing for regular automatic operation, with hand operation in case of emergency. Allen-Bradley Co., Milwaukee, Wis.

Pyranol.—Bulletin GEA-1886, 4 pp. Pyranols, cooling and insulating materials which have, in addition to the desirable characteristics of mineral oil, the distinctive properties of being non-inflammable and non-explosive, are described. Approximately 50,000 kva of Pyranol capacitors and more than 25,000 kva of Pyranol transformers are in service, and Pyranol treated paper cable is commercially available for cable rated at 600 volts and below. General Electric Co., Schenectady, N. Y.

Hour Counter.—Bulletin K-2, 4 pp. Describes the new Weston hour counter for the measurement of elapsed time. This device is a compact, small instrument, weighing slightly more than a pound, with dials indicating hour runs up to 9,999 and repeats. It was developed for use in connection with units of electrical equipment which have a rather definite life in hours of operation and which it is desired to replace at the end of the indicated life rather than wait for failure before replacing. Among its most important applications are those in conjunction with devices using vacuum tubes. Weston Electrical Instrument Corp., Newark, N. J.